WILDLIFE AND OCEANS IN A CHANGING CLIMATE

OVERSIGHT HEARING

BEFORE THE

SUBCOMMITTEE ON FISHERIES, WILDLIFE AND OCEANS

OF THE

COMMITTEE ON NATURAL RESOURCES
U.S. HOUSE OF REPRESENTATIVES

ONE HUNDRED TENTH CONGRESS

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Tuesday, April 17, 2007
U.S. House of Representatives
Subcommittee on Fisheries, Wildlife and Oceans
Committee on Natural Resources
Washington, D.C.

The Subcommittee met, pursuant to call, at 10:02 a.m., in Room 1324, Longworth House Office Building, Hon. Madeleine Z. Bordallo, [Chairwoman of the Subcommittee] presiding.

Present: Representatives Bordallo, Brown, Kildee, Kennedy, Capps, Gilchrest and Sali.

STATEMENT OF THE HONORABLE MADELEINE Z. BORDALLO, A DELEGATE IN CONGRESS FROM THE REPUBLIC OF GUAM

Ms. BORDALLO. The oversight hearing by the Subcommittee on Fisheries, Wildlife and Oceans will now come to order. The Subcommittee is meeting today to hear testimony on the effects of climate change on wildlife and on our oceans. Under Committee Rule 4(g), the Chairman and the Ranking Minority Member can make opening statements. If any other Members have statements, they can be included in the hearing record under unanimous consent.

This morning's hearing will focus on the effects of climate change on wildlife and oceans. Once a phenomenon discussed almost exclusively by scientists, climate change has moved front and center in the discussion amongst policymakers, businesses, and citizens all over the world.

We are no longer dealing with the question of if climate change is occurring; we are now addressing what we can do.

The warming of the climate system is unequivocal and is now evident worldwide, according to a report issued earlier this year by the Intergovernmental Panel on Climate Change. We are seeing increases in global air and ocean temperatures, widespread melting of snow and ice, rising global average sea level, and changes in ocean salinity, precipitation, heat waves, and the increased intensity of tropical storms.

On April 6th, a second IPCC report concluded that observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases. Climate change will negatively affect our coasts, our wetlands, and mangroves through increased

erosion and sea level rise. Global warming is affecting corals through increases in sea surface temperatures and acidification and affecting wildlife through the loss of preferred habitat and changes in seasonal migration patterns.

I am personally concerned with the report's specific predictions of the detrimental effects of climate change on small island communities. While coral reefs are prized for their beauty and diversity worldwide, they are invaluable to those of us in small island communities who depend on them as a valuable resource and as a protection from severe storms such as typhoons.

As we will hear today, scientists are observing and predicting detrimental effects of climate change not only on our oceans and corals but also on a great number of other animals, such as migratory birds, tigers, trout, polar bears, and sea turtles.

The purpose of this hearing is to shed light on the impacts of climate change and additional factors which can have global warming impacts, including habitat degradation and loss, invasive species, disease, pollution, poaching, and overfishing. We are looking at what we can do to address the effects of climate change on our oceans and wildlife.

As Peter Ewins, the Executive Director of the British Meteorological Office said in a letter to the world's press in 1999, "Ignoring climate change will be the most costly of all possible choices for us and for our children."

As Chairwoman, I now recognize Mr. Brown, the Ranking Republican Member, for any statement he may have.

[The prepared statement of Chairwoman Bordallo follows:]

Statement of The Honorable Madeleine Z. Bordallo, Chairwoman, Subcommittee on Fisheries, Wildlife and Oceans

This morning's hearing will focus on the effects of climate change on wildlife and oceans. Once a phenomenon discussed almost exclusively by scientists, climate change has moved front and center in the discussion amongst policymakers, businesses, and citizens all over the word. We are no longer dealing with the question of if climate change is occurring; we are now addressing what we can do.

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STATEMENT OF THE HONORABLE HENRY E. BROWN, JR., A REPRESENTATIVE IN CONGRESS FROM THE STATE OF SOUTH CAROLINA

Mr. BROWN. Thank you. Madam Chairwoman, I want to compliment you for holding this oversight hearing on the impact of a change in climate on our wildlife and oceans.

This is an issue that is generating tremendous debate and controversy. There are those people who believe that our changing climate is the greatest crisis facing mankind today. Conversely, there are others who believe this is a great hoax on the American people and a less than subtle way of radically changing our way of life.

I come to this hearing with an open mind, and I intend to carefully listen to the testimony of each of our witnesses. I am looking for facts and solutions and not unproven theories. I also reject the politics of fear and believe it is shameful that any citizen would have their life threatened because they dare to articulate a different point of view.

While there is significant evidence that the earth is now getting warmer, there is no consensus how long this period may last, whether increased temperatures are permanent and what long-term impact carbon emissions may have on fish and wildlife species.

What we do know is that radical shifts in temperature patterns is not a new phenomenon. Climatologists have been studying weather trends for the past 15,000 years. During this time, this planet has experienced many warming and cooling periods, including the Medieval Warm Period and the Little Ice Age.

In fact, as recently as 30 years ago the scientific consensus was that we were entering a new ice age and that a drop of only one degree Celsius would result in a world famine. The January 31, 1977, cover Time magazine was entitled The Big Freeze. The scientists were wrong in 1977, they were wrong about last year's summer hurricane season, and they may well be wrong about the so-called catastrophic events of the current warming trend.

Having just experienced the coldest Easter Sunday in Charleston in over 50 years, a few of my constituents would have enjoyed a little global warming. It is also a fact that this month in snowed in Dallas, Texas, for the first time in 70 years. There were record low temperatures in Charlotte, North Carolina; Little Rock, Arkansas; and Jacksonville, Florida, and the recently completed Masters Golf Tournament in Augusta, Georgia, was the coldest ever. Could this be the beginning of a new ice age?

We will hear today from our witnesses that carbon dioxide emissions should be reduced by 80 percent by the year 2050. We will also hear that in order to stop the ill-effects of global climate change we will need to return to preindustrial emission levels of carbon dioxide. How realistic are these requests?

I read in the written testimony that manmade levels of carbon dioxide in the atmosphere are three percent of the overall total. Am I to understand that we need to reduce this amount by 80 percent in order to stop or reverse global climate change?

It is my firm belief that before we as a nation commit to spend $100 to $400 billion dollars a year in taxpayer money to reduce emissions to Kyoto Treaty levels, we must understand the consequences of global warming and the urgency of our actions.

As the former chairman of the South Carolina Ways and Means Committee, I can tell you that a carbon tax could have a devastating impact on our economy. It would literally be a Federal tax on breathing. As an alterative, we should consider tax credits and incentives to reduce carbon emissions.

Finally, in the next five years China and India will build 800 new coal-fired power plants. These plants are expected to emit 2.5 billion tons of carbon dioxide each year into the atmosphere. This is more than five times the amount of reductions mandated by the Kyoto Accords. How is the international community going to address this amount of emissions which is nearly twice what we now produce in the United States?

Nevertheless, it is important to hear how potential climate conditions may affect our wildlife within the National Wildlife Refuge System and our ocean fishery resources. Since the United Nations Intergovernmental Panel on Climate Change has recently concluded that over the next century sea levels will rise between seven and 23 inches, it is important to examine the potential consequences of this development.

Thank you, Madam Chairwoman.

[The prepared statement of Mr. Brown follows:]

Statement of The Honorable Henry E. Brown, Jr., Ranking Republican Member, Subcommittee on Fisheries, Wildlife and Oceans

Madam Chairwoman, I want to compliment you for holding this oversight hearing on the impact of a changing climate on our wildlife and oceans.

This is an issue that is generating tremendous debate and controversy. There are those people who believe that our changing climate is the greatest crisis facing mankind today. Conversely, there are others who believe this is a great hoax on the American people and a less than subtle way of radically changing our way of life.

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What we do know is that radical shifts in temperature patterns is not a new phenomena. Climatologists have been studying weather trends for the past 15,000 years. During this time, this planet has experienced many warming and cooling periods including the Medieval Warm Period and the “Little Ice Age”. In fact, as recently as 30 years ago, the scientific consensus was that we were entering a new ice age and that a drop of only 1 degree Celsius would result in world famine. The January 31, 1977 cover of Time magazine was entitled “The Big Freeze”. The scientists were wrong in 1977, they were wrong about last year’s summer hurricane season and they may well be wrong about the so-called catastrophic effects of the current warming trend.

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Thank you, Madam Chairwoman.

Ms. BORDALLO. I want to thank the Ranking Member, Mr. Brown.

I understand from the staff that we are having technical problems. We will take a short recess.

[Recess.]

Ms. BORDALLO. I understand from committee staff that there has only been one other technical problem with our recorders, and that was 15 years ago, so I guess we are doing very well.

I would now like to recognize our witnesses. The witnesses will testify in two panels. The first panel will address the effects of climate change on wildlife, and this panel will include Mr. William McKibben, an author and scholar in residence in the Department of Environmental Studies at Middlebury College; Dr. Joshua Lawler from the College of Forest Resources at the University of Washington; Dr. Terry Root from the Center for Environmental Science and Policy at Stanford University; Monica Medina, who is the Acting Director for the International Fund for Animal Welfare in the United States; and Dr. Christopher Haney, who is the Chief Scientist for the Defenders of Wildlife here in Washington, D.C.

I want to thank all of the witnesses for being here today, and the Chairwoman would now recognize Mr. McKibben to testify for five minutes.

I would note for all witnesses that the timing lights on the table will indicate when your time has concluded, and we would appreciate your cooperation in complying with the limits that have been set as we have many witnesses to hear from today. Be assured that your full written statement will be submitted for the hearing record.

And now I would like to introduce Mr. McKibben.

STATEMENT OF WILLIAM McKIBBEN, AUTHOR AND SCHOLAR IN RESIDENCE, MIDDLEBURY COLLEGE

Mr. MCKIBBEN. Thank you very much. Thank you for the opportunity to testify before this committee and for the chance to share with you not in my case new science, but some very fresh evidence of Americans' passion for taking strong action on global warming.

I am a writer, an environmentalist. My first book, The End of Nature, in 1989 was also generally acknowledged as the first book for a general audience about global warming. In the years since, I have watched with some dismay as Congress has failed to respond in a serious way to that challenge and am very glad to see from your interest here today that that situation may be changing.

It is because of that failure that I helped to organize Stepitup07.org. Last summer, in my home State of Vermont, a few of us organized a five-day, 50-mile walk to ask for Federal action on climate change. It was a successful venture, drawing 1,000 walkers by its finish in Burlington. In Vermont, 1,000 people is a lot of people.

We were chagrined to read in the newspaper the next day that those 1,000 people may have represented one of the largest numbers of Americans yet to gather in one place in this country to protest climate change. That seemed to some of us a situation that needed to change.

In January of this year, we launched a website, Stepitup07.org, asking people to organize rallies in their communities on April 14 to demand that Congress pledge to cut carbon emissions 80 percent by 2050. By we, I mean myself and six students who had graduated from Middlebury College where I teach in the preceding six months.

We had no money and no organization and so there was no reason other than our own willingness to work hard to think we would be able to organize a significant number of protests. Our secret hope was that we might convince people in 100 locations around the country to schedule demonstrations that day.

Instead, three days ago there were rallies in more than 1,400 communities in every state in the union. This is due to the fact that Americans are very eager for real and dramatic action on this issue. For many years it had seemed too large and daunting an issue for most of us to get our hands around, especially since any action in Washington was blocked by committee chairs who refused to take the issue seriously.

Even as we performed the necessary individual steps—screwing in compact fluorescent lightbulbs say—many of us were left thinking that those steps had a token quality and that they needed strong Federal action to make them real.

The geographic and demographic diversity of these protests was astonishing. From the day we opened our website, we were heartened to see the participation of a wide variety of Americans from the founders of the Evangelical Environmental Network to sorority chapters to League of Women Voters clubs, all of them rallying behind the standard cut carbon 80 percent by 2050.

People participated with great creativity. In Florida they organized underwater demonstrations off the endangered coral reefs of the Keys, one of the nation's most glorious wildlife habitats which cannot survive the anticipated temperature rises of this century.

Others in the Sunshine State rallied in the parking lot of the Jacksonville Jaguars football stadium, hoisting a boat with a crane 20 feet in the air to show where sea levels might fall should the melt of the great ice sheets proceed unabated.

In lower Manhattan, people in blue shirts thronged into the streets of lower Manhattan to form a human sea along the line where the tide may someday rise. In Seattle, they hoisted giant salmon puppets to the new tideline. In the Rockies, Sierras and Cascades, skiers descended down many of the fast-dwindling glaciers in formation.

Everywhere in the country, people used the backdrop of their every day lives to try and show what some of the effects of climate change would be on their lives. Children and pregnant women were at the front of many marches, symbolizing the stake that our youngest have in the changes that will play out over their lifetimes.

Elsewhere people paid tribute to the many parts of creation put at risk by our carelessness from reef fish to maple trees, from those animals that need the snow of winter to those plants who will not survive a hotter and more arid world.

Though this was an entirely citizen organized day of action which depended on neither political nor entertainment celebrities to draw its crowds, I am happy to say that many of your colleagues in both chambers and from both parties attended rallies in their local areas.

I believe that there were demonstrations in almost all your districts, and we have distributed some of the first pictures to come back in from your districts today to you in your packets. It was an impressive sight and one I urge you to see, the largest grassroots environmental gathering since Earth Day 1970, widely covered in the media. There are archived photos of all actions at Stepitup07.org.

Our hope is that just as Earth Day 1970 helped usher in bold policy making, this day of action will do so as well. Our definition of bold action is cuts of at least 80 percent in American carbon emissions. They need to begin right away and be sustained for many years, a process that should begin with a moratorium on new coal-fired generating stations.

Young people in particular are impatient to see this transition underway, and I would like to as I finish introduce my colleagues who made this happen, the eight young people who served as core organizers to this national effort and are here today: Julia Proctor, Jeremy Osborn, Robbie Adler, John Warnow, Jamie Henn, Phil Aroneanu, May Boeve and Will Bates.

They are outstanding examples of the reasons that we must address this problem and also of the reasons that we can. Thank you for joining them and me in this task.

[The prepared statement of Mr. McKibben follows:]

Statement of Bill McKibben, Author and Scholar in Residence, Middlebury College

Thank you very much for the opportunity to testify before this committee, and for the chance to share with you some very fresh evidence of Americans' passion for taking strong action on global warming.

I am a writer and environmentalist. My first book, The End of Nature in 1989, was also generally acknowledged as the first book for a general audience about global warming. In the years since, I have watched with some dismay as Congress has failed to respond in a serious way to that challenge, and am very glad to see from your interest here today that that situation may be changing.

It is because of that failure that I helped to organize Stepitup07.org. Last summer, in my home state of Vermont, a few of uanized a five-day, 50-mile walk to ask for federal action on climate change. It was a successful venture, drawing a thousand walkers by its finish in Burlington. (In Vermont, a thousand people is a lot). But we were chagrined to read in the newspaper the next day that those thousand people may have represented one of the largest numbers of Americans yet to gather in one place in this country to protest climate change. That seemed to some of us a situation that needed to change.

On January 10 of this year, we launched a website, stepitup07.org, asking people to organize rallies in their communities on April 14 to demand that Congress pledge to cut carbon emissions 80% by 2050. By "we" I mean myself and six students who had graduated from Middlebury College, where I teach, in the proceeding six months. We had no money and no organization, and so there was no reason other than our own willingness to work hard to think that we would be able to organize a significant number of protests. Our secret hope was that we might convince people in a hundred locations around the country to schedule demonstrations that day.

Instead, three days ago, there were rallies in more than 1,350 communities in every state of the Union. This is not due to our skill as organizers—it is due to the fact that Americans are very eager for real and dramatic action on this issue. For many years it has seemed too large and daunting an issue for most of us to get our hands around, especially since any action in Washington was blocked by committee chairs who refused to take the issue seriously. Even as we performed the necessary individuals steps—screwing in compact fluorescent light bulbs, say—many of us were left thinking that those steps had a token quality, and that they needed strong federal action to make them real.

The geographic and demographic diversity of these protests was astonishing. From the day we opened our website, we were heartened to see the participation of a wide variety of Americans. One of the founders of the Evangelical Environmental Network, Calvin DeWitt, wrote one of the first blog posts. One of the first evidences of support from campus came from the Alpha Phi sorority chapter at the University of Texas at Austin, where more than a hundred women posed behind our banner: Step It Up Congress, Cut Carbon 80% by 2050. ("We wanted to show it wasn't just hippies who cared," they wrote). League of Women Voters chapters, senior citizens homes, local congregations, bike clubs, garden societies, and many, many others participated. And participated with great creativity: in Florida, people organized an underwater demonstration off the endangered coral reefs of the Keys, one of the nation's most glorious wildlife habitats which cannot survive the anticipated temperature rises of this century. Others in the Sunshine State rallied in the parking lot of the Jacksonville Jaguars demonstration, hoisting a boat via crane 20 feet in the air to show where sea levels might fall should melt of the great ice sheets proceed unabated. In lower Manhattan, people in blue shirts thronged into the streets of lower Manhattan to form a human sea along the line where the tide may someday rise. In Seattle, they hoisted giant salmon puppets to the new tideline, and in the Rockies, Sierras, and Cascades, skiers descended down many of the fast-dwindling glaciers in formation. Everywhere in the country, people used the backdrop of their everyday lives to try and show what some of the effects of climate change would be on their lives. Children and pregnant women were the front of many marches, symbolizing the stake that our youngest have in the changes that will play out over their lifetimes. Elsewhere, people paid tribute to the many parts of Creation put at risk by our carelessness, from reef fish to maple trees, from those animals that need the snow of winter to those plants who won't survive a hotter and more arid world. Though this was an entirely citizen-organized day of action, which depended on neither political nor entertainment celebrities to draw its crowds, I am happy to say that many of your colleagues in both chambers and from both parties attended rallies in their local areas. I believe that there were demonstrations in almost all your districts, and you will receive pictures and descriptions of those gatherings at your district offices in the days to come. It was an impressive sight, and

one I urge you to see—the largest grassroots environmental gathering since Earth Day 1970, widely covered in the media. Archived photos of all the actions are available at stepitup07.org.

Our hope is that, just as Earth Day 1970 helped usher in bold policy making like the Clean Air and Clean Water Acts, this day of action will be one of the catalysts for bold action in this legislative session. Our definition of bold action is cuts of at least 80% in American carbon emissions by 2050. There is no study that says 81% would be too much and 79% too little. Instead, it is a target broadly in line with the message the scientific community has been sending with increasing urgency: we need to begin deep cuts right away and sustain them for many years, transforming the American energy economy in the process, a process that should begin with a moratorium on new coal-fired utilities. That transition will be painful for some interests, but beneficial to many more—a green economy is clearly the economy of the future, and clinging to the bulwarks of last century's economy simply because they are familiar implies a timidity both unbecoming and un-American. Young people in particular are impatient to see this transition underway. Starting soon is imperative, especially to send a strong signal to those anticipating capital investments in coming years, a signal that it would be folly to continue calculating carbon emissions as a free good with no economic cost. Starting soon is imperative, as well, because America needs very badly to re-engage in the international negotiations around climate change. Our neglect of our international responsibilities in this regard has been a dangerous failure.

As you know, our record on containing our carbon emissions is poor. Every year since I wrote The End of Nature in 1989, carbon emissions have grown about one percent annually. The administration recently predicted that rate would hold at least through 2020. That flies in the face of efforts by every other developed nation, and it flies in the face of science and chemistry. Had we started twenty years ago to make the necessary changes, we could have proceeded gradually. Sadly, your predecessors in Congress neglected to do so, meaning that you will have to take more uncomfortable steps to address the problem. We are confident that changes in both technology and daily habit make the goals of our demonstrations achievable—after all, citizens of western Europe enjoy similar quality of life on half the per capita energy use—but we do not imagine they will be simple. You will be under much pressure from special interests to go slowly, and it's possible that even minimal progress will be cheered in some quarters. But if our rallies, and the many other efforts organized by others in months past and to come, have any meaning, it is this: the bar has been raised. Americans who know and care about this issue—and their number grows daily—want nothing less than action on a scale that actually addresses the problem. The phrase "Step It Up" that we chose for our actions was aimed squarely at you and your colleagues. We hope very much that you are listening.

In closing let me thank the six young people who served as the core organizers of this national effort: Jeremy Osborn, Jon Warnow, Jamie Henn, Phil Aroneanu, May Boeve, and Will Bates are outstanding examples of the reasons we must address this problem, and of the reasons that we can. Thank you for joining them and me in this task.

Response to questions submitted for the record by William McKibben

QUESTIONS FROM THE HONORABLE PATRICK KENNEDY

Regardless of whether or not we take actions to control and reduce green house gas emissions, wildlife and wildlife habitat and the ocean environment are going to change and adapt, often unpredictably, to a warming climate. Consequently, we should take steps now to develop strategies to allow for the future conservation of biodiversity and the maintenance of a healthy and resilient environment.

1. **Keeping in mind that any transition to a new "Green Economy" will take decades to achieve and that most Members of Congress will want to limit unnecessary disruptions of social and economic systems, can you be more specific on what practical types of adaptive management strategies we should consider to mitigate the negative effects of climate change on our collective wildlife and ocean resources?**

Think North-south corridors: Adirondacks to Algonquin, Yellowstone to Yukon, etc.

2. Should we be doing more to re-evaluate our current policies for land use planning and public acquisition of land for wildlife habitat? Should we be adopting a broader landscape and ecosystem-based approach for protecting wildlife?

The Nature Conservancy is doing extremely valuable work along these lines—landscape-scale planning.

3. Finally, how might such ideas be applied to the ocean and coastal environment and the wildlife therein?

The more severe these problems get, the bigger the boundaries of our refuges and wildernesses need to be.

QUESTIONS FROM THE HONORABLE HENRY BROWN, MINORITY RANKING MEMBER

1. Mr. McKibben, while I understand you have written several books on the environment, do you have any advanced scientific degrees? What is the source of your data?

All my advanced degrees are honorary. My data comes from many sources, reflected in the voluminous footnotes of my books; if you have particular questions about particular data, I'd be happy to help you track down the sources.

2. If in fact you are correct that "Climate change is the greatest threat civilization now faces", why are you suggesting we wait 45 years to reduce carbon emissions by 80 percent? Why not mandate those cuts in carbon emissions now?

I think you'd be very wise to do them faster, and am very glad you are thinking along those lines. We have perhaps erred on the side of being too politically realistic.

3. What is the cost and who will pay the price for reducing carbon emissions by 80 percent?

The cost will depend on how it's done, of course. The transition away from fossil fuel should provide the next great technological project for America, and hence will yield economic benefits. At the same time, fossil fuel has been so extraordinarily cheap that we will notice the change. As the Stern report for the UK government pointed out last year, however, the cost of not making this change will be orders of magnitude higher.

4. What is the cost to the United States to comply with the Kyoto Treaty?

There's been no cost because the United States hasn't ratified the treaty. The cost of not doing so has been very high in terms of damage to the environment, damage that will be playing out for a long time to come.

5. Ben and Jerry's Ice Cream is produced in your state. A single gallon of their ice cream requires massive amounts of electricity to make and refrigerate and four gallons of milk produced by cows that generate gallons of manure and methane gas. This does not include the hay they eat, the tractor fuel, chemical fertilizers, herbicides and insecticides and the fuel used by planes, trains and trucks to transport Ben and Jerry's Ice Cream to local supermarkets throughout the country. Isn't Ben and Jerry's a major contributor to green house gas emissions? It has been reported that the typical breakdown of carbon dioxide in the atmosphere is 57 percent from the ocean, 19 percent from decaying vegetation, and 19 percent from plant and animal respiration. Do you agree with this breakdown? If not, what is it?

Though, like Ben and Jerry's ice cream, I come from Vermont, I am not privy to their precise accounting system. Your breakdown seems reasonable, and underscores the point that every item on the store shelf has substantial embedded energy in it; I can't think of any reason why Ben and Jerry's would be any more culpable than anyone else, and their efforts on a wide range of environmental and social issues should be applauded. In my new book, Deep Economy, I advocate trying to foster more localized economies for precisely this purpose; if we can bring more food processing closer to home we'll be able to stabilize the rural communities where I've spent my life and at the same time reduce carbon emissions.

6. Is the statement by the current issue of Newsweek accurate that "Coal is the cheapest and dirtiest source of energy around. If we cannot get a handle on the coal problem, nothing else matters"?

It is.

7. What are your thoughts on the "urban heat island effect" where heat is trapped in cities during the day and released into the atmosphere at night? Is this a valid theory for global warming?

All climate models that I know of account for the urban heat island effect, which is well known and easily modeled.

8. Should the Congress consider enacting a carbon tax? What would be the rate of the tax, who would pay them and what happens to the proceeds collected by the Internal Revenue Service?

It would be a very straightforward way to address the problem. Many who have studied it have concluded that Congress won't enact a tax because political leaders fear the very word tax—I'm glad to see this attitude may be changing. If you do enact a tax, you should do so in such a way that the revenue gained is offset by tax reductions elsewhere. For instance, it might well make sense to eliminate the payroll tax (a tax, after all, on something we would like to encourage, employment) and replace it with a tax on carbon, something we wish to avoid. As an alternative, you might wish to consider the excellent plans put forward by people like Peter Barnes for a 'skytrust,' that would rebate money through a formula not unlike the Alaska Permanent Fund.

9. By the year 2012, China and India will build 800 new coal-fired power plants that will emit 2.5 billion tons of carbon dioxide into the atmosphere. How should the international community respond to this issue?

Not by trying to scapegoat China and India. Even in 2012, per capita the Chinese will be using a quarter as much energy as Americans, and India considerably less than that. And of course they are new to the game of burning carbon—recent estimates suggest that it will be 40 years before their contribution to global warming, even with their very large populations, will approach ours. We have no moral leg to stand on to demand their participation in any international regime on climate controls, but we can work hard—through technology transfer especially—to encourage them to shift the trajectory of their individual development. That we did not do so six years ago when their energy takeoff was beginning will be considered by historians an episode of epic folly on our part.

10. Do you or have you (or your organization) received any funding from the Pew Charitable Trust or the David and Lucille Packard Foundation? If so, please elaborate.

No

11. Are you currently a party to any law suit against the Department of the Interior or the Department of Commerce (or any of the agencies within these departments)? If so, please describe.

No. I've never sued anyone in my life.

QUESTIONS FROM THE HONORABLE WAYNE GILCHREST

1. If paleo-records show that corals existed in the past under high atmospheric CO_2 concentrations, why is it a problem now?

2. Among the various effects of climate change to wildlife and the oceans, are there issues that are more pressing than the others? Why?

3. In the U.S., as plant and animal species migrate north and to higher elevations, what does that mean for the regions they leave behind? For instance, it has been said that some U.S. states that border Canada might actually benefit from the next few decades of climate change, but what will it mean for the states further to the South, and especially those on the coast?

Any benefit from climate change will be transient at best, and even then unlikely. I live in a state that borders Canada—our 'benefit' would, I guess, be warmer winters, but most Vermonters cherish the winter season. And we will lose, or so the computer models indicate, our birch-beech-maple forest with its fall climax of color, and our spring syrup season. No wonder Vermonters are so outspoken in their demand for federal action on global warming.

4. **How do shifts in habitat range of plants and animals affect human interests such as agriculture or the spread of invasive species and diseases? How can we adaptively plan for such changes?**
5. **The IPCC reports with 80% certainty that the changes in water temperatures, ice cover, salinity and ocean circulation are impacting the ranges and migration patterns of aquatic organisms. How will this affect management and use of these resources, and how can we prepare for any changes?**
6. **In the Chesapeake Bay, we are losing marshland to rising sea levels. Can you talk about what is happening to coastal wetland areas in other areas of the country and what that is doing to their ecosystems and the local economies that depend upon these natural resources?**
7. **What role do marshlands play in sequestering carbon? Is marsh restoration a viable alternative in carbon sequestration?**
8. **The latest IPCC report warns that ocean acidification poses a threat to coral reefs and shell-forming organisms that form the base of the aquatic food chain. But the report says more study is needed to determine the full scope of the threat. What do we know about the potential impacts to U.S. coastal ecosystems today and how quickly is our understanding of acidification improving? What can Congress do to improve upon this understanding? Do we know enough to act?**
9. **What additional resources or tools will the Fish and Wildlife Service and National Marine Fisheries Service need to adequately prepare and address the impacts of global warming on wildlife over the next decade?**
10. **We've heard a lot about the polar bear and the petition to list the species under the Endangered Species Act (ESA). Opponents of listing claim that the effects of global warming are in fact unclear. What evidence is there that global warming is already having a dramatic effect on the species across its range? How will an ESA listing help polar bears?**
11. **Dr. Sharp's testimony stated that anthropogenic CO_2** *emissions are approximately 3% within the global CO_2 cycle. How does this translate to such large effects on the planet? Please also clarify how this number relates to the 80% carbon emissions cut by 2050 proposed by stepitup07.org.*

The global carbon cycle was well balanced before anthropogenic emissions began with the Industrial Revolution. Our additional increment has upset that balance—imagine a person who has maintained the same weight for decades and then begins eating an additional slice of pie every night at dinner. It adds up quickly.

Recent scientific assessments indicate that an 80% reduction in our carbon emissions—if it began rapidly and was coupled with strong attempts to help developing countries work in the same direction—might be enough not to head off global warming but to limit it below truly catastrophic levels. I should stress the need for rapid change. James Hansen of NASA, our foremost climatologist, has given us a window of one decade (now nine years) to reverse the flows of carbon into the atmosphere or else face a situation of almost certain melt of the great ice sheets above Greenland and the West Antarctic. Such a melt would raise sea levels dramatically, endangering much of human civilization.

Ms. BORDALLO. Thank you very much, Mr. McKibben.

Would the students please stand that were mentioned?

[Applause.]

Ms. BORDALLO. Thank you very much.

Before I introduce the next witness, I would also like to recognize the gentleman from Rhode Island, Mr. Kennedy, who has joined us.

Now I recognize Dr. Lawler to testify for five minutes.

STATEMENT OF JOSHUA J. LAWLER, Ph.D., COLLEGE OF FOREST RESOURCES, UNIVERSITY OF WASHINGTON

Dr. LAWLER. Madam Chairwoman, I would like to thank you and the committee for inviting me to speak on this important issue.

If we could have the first slide? I am going to show some images with my testimony.

[Slide.]

Dr. LAWLER. I am going to present research that my colleagues and I have done to look at the potential effect of 30 different future climate change projections on roughly 3,000 species of amphibians, mammals and birds in the western hemisphere. These are climate projections from the latest IPCC Fourth Assessment Report Initiative.

We chose 30 projections from 10 different general circulations models and three different emissions scenarios. The emissions scenarios are a higher A2, an intermediate A1B scenario, and a lower B1 scenario. The projections I am going to show you are for roughly 80 years from today for a 30-year period.

This is what these climate change projections look like. These are shifts in species ranges. This is a shift in the range of the northern flying squirrel. The light green area you see is where the range is predicted to be stable. The dark green area is where the range is predicted to expand. The pink area is where the range is expected to contract.

This is one of 30 projections we made for this species. We made 30 projections for each of those 3,000 species. There are roughly 90,000 maps like this that go into the next image that I am going to show you.

These are images of what I am calling species turnover or species change, and it is a percent change in the animals across the western hemisphere. The change is measured as potential loss in species due to a range contraction plus potential gain in species due to a range expansion expressed as a percentage of the current species, so it is a percent change. They take into account the 30 different climate change projections.

These maps represent 80 percent of the climate change projections predict at least this much change. For example, 80 percent of the climate change projections predict between 20 and 30 percent change in the animal communities in the wildlife across the United States under the lower scenario. Eighty percent of the climate change projections result in at least 30 to 40 percent change in the wildlife at the higher A2 scenario.

In the higher A2 scenario there are changes in areas such as Texas and parts of the southwest that are as large as 50 to 60 percent. These are large changes, and these maps represent in many cases a wholesale change in the wildlife in many areas in the western hemisphere for the next 80 years.

These are conservative estimates for a number of reasons, and I will give you three of those reasons. First of all, we didn't model all the species in the western hemisphere. We couldn't model some. The ones we couldn't model are the ones that are likely to be most sensitive to change, so the maps I just showed you, if we could model those other species, would be a lot redder. The numbers would be a lot higher.

They are conservative because species interact. If you take one species out of a system or you put one species into a system, there can be a cascade of ecological events that can be much greater than just adding or subtracting a species.

They are also conservative because we didn't take into account the effect of climate change on fire regimes, hydrological regimes and other disturbance regimes which will further change habitat.

I have three conclusions. First of all, despite the variability in climate change projections, and you know there is a great amount of variability in projected future climate. Despite that variability, these analyses show a clear effect of climate change on wildlife.

The second conclusion is that even moderate changes in climate, even the lower climate change projections, produce significant changes for wildlife. Finally, larger changes in CO_2 emissions result in larger changes for wildlife.

These conclusions lead to three recommendations that I have. The first of these is that reducing CO_2 emissions and greenhouse gas emissions will reduce the effect on wildlife.

The second is that we need to manage these wildlife species if we want to preserve these wildlife species. We need to manage them and the systems in which they live for change. We need to manage them as dynamic changing systems.

The third recommendation is that because these species are going to move and because they are going to move quite a bit, we are going to need to coordinate our efforts to manage them across Federal agencies and across the lands at large spacial scales on which they exist.

That is all I have.

[The prepared statement of Dr. Lawler follows:]

Statement of Joshua J. Lawler, Assistant Professor, College of Forest Resources, University of Washington

Summary

Recent shifts in species ranges have been linked to recent changes in climate. Projected future climatic changes are likely to result in even more drastic shifts in species ranges in the coming century. Research I have conducted in conjunction with colleagues at three other universities and two federal agencies indicates that in many regions of the western hemisphere, climate change will likely result in a wholesale reorganization of vertebrate communities. We modeled the potential effects of 30 different climate-change projections on the geographic ranges of 2,954 vertebrate species. We then identified areas in which the majority (80%) of the climate projections resulted in large predicted changes in animal assemblages. Large portions of both North and South America are projected to experience at least 20-30% species turnover under even the lower B1 greenhouse-gas emissions scenario and at least 30-40% species turnover under the mid-high A2 scenario. Parts of the Andes, Central America, and the far northern boreal forests and tundra are predicted to experience greater than 80% species turnover. Thus, our results indicate that in the coming century, vertebrate communities in many parts of North and South America will likely bear little resemblance to today's fauna.

Background

Recent shifts in the distribution of plants and animals have been clearly linked to recent changes in climate (Parmesan and Yohe 2003, Root et al. 2003, Parmesan 2006). Most notably, species have shifted their ranges either poleward in latitude or upward in elevation (Parmesan 1996, Parmesan et al. 1999, Thomas and Lennon 1999). These movements have generally occurred at rates that are consistent with rates of recent global warming (Parmesan and Yohe 2003, Root et al. 2003).

Climatic changes for the coming century are projected to exceed those of the past 100 years. For example, global average temperatures have risen approximately 0.7°C in the past century and are projected to increase between 1.1 and 6.4°C in

the next 100 years (Alley et al. 2007). Given the projected magnitude of future climatic change, we can logically expect even greater shifts in species distributions in the coming century.

Several studies have made projections of potential future shifts in the distribution of both plants and animals (e.g., Peterson et al. 2002, e.g., Thuiller et al. 2005, Araújo et al. 2006). In general, these studies have predicted relatively large changes in local plant or animal assemblages as a consequence of projected changes in climate. For example, Peterson et al. (2002) estimated that changes in some assemblages of animals in Mexico will potentially be as high as 40% by 2055. Thuiller et al. (2005) estimated average changes in plant assemblages across Europe will range from 27-63% by 2080.

Changes in the distribution of species have profound implications for the management of fish and wildlife. Areas that currently provide habitat for a given species may no longer provide habitat in the future. Conversely, areas that are unsuitable today may eventually provide habitat as the climate changes. In addition, the loss of a key species or the addition of a specific species to a community may have profound effects on the other species in the system. Thus, shifts in even small numbers of species have the ability to dramatically alter ecological systems. For example, the climate-induced spread of the mountain pine beetle has increased whitebark pine mortality in parts of the Rocky Mountains resulting in the reduced availability of whitebark pine seed, a primary winter food source for the grizzly bear (Logan and Powell 2001).

Projected climate-induced impacts on animal distributions in the western hemisphere

Here, I present research that my colleagues and I have done to assess the potential effects of climate change on the distribution of animals in the western hemisphere. We explored the potential effects of 30 coupled atmosphere-ocean general circulation model (AOGCM) future-climate simulations on the distribution of 2,954 species of birds, mammals, and amphibians for the period of 2071-2100. We then identified areas where animal assemblages are consistently predicted to experience changes.

Study approach

We built individual models for each species in the study based on the relationships between observed species ranges and current climate. This general modeling approach is often called "climate envelope" or "species niche modeling" (Pearson and Dawson 2004). More specifically, we used random forest classifiers (Breiman 2001) a consensus-based ensemble modeling approach that involved building 100 individual models for each of the species in the study and then averaging the predictions from those models to produce one prediction. Random forest classifiers have been shown to outperform other similar modeling approaches (Lawler et al. 2006). We used only highly accurate models in our analyses. We tested the models on a reserved set of data that was not used in the model-building process. We then removed any species from the study for which the models were unable to predict at least 90% of the presence data points and at least 80% of the absence data points correctly. This provided us with a set of models that is more accurate than most of those used in previous range-shift studies. After building and selecting the models, we then used the 30 future climate projections as input into the models to generate 30 potential future geographic ranges for each species.

The 30 climate simulations used in the study consisted of projections from 10 AOGCMs (Table 1) run under three different greenhouse-gas emissions scenarios (B1, A1B, and A2) representing the lower, mid, and mid-high range of the scenarios developed for the IPCC Special Report on Emissions Scenarios (SRES) (Nakicenovic et al. 2000). All 30 simulations have been produced for the IPCC Fourth Assessment Report initiative. For North and South America, these 30 distinct climate simulations produced increases in mean annual temperature ranging from 1.2 to 5.2°C and changes in mean annual precipitation ranging from -122.5 to 131.9 mm for the 30-year time period relative to 1961-1990. These climate simulations thus represent the uncertainty in both future greenhouse-gas emissions and in the simulated response of the climate system (Cubasch and Meehl 2001).

To summarize the projected range shifts across all species and climate-change scenarios, we used each of the 30 climate-change projections to estimate potential changes in animal assemblages for each of 15,323 50x50-km grid cells in the western hemisphere. As climate changes, species will differ in their ability to track the change and to move into newly created suitable habitat. We calculated potential changes on a cell-by-cell basis assuming no dispersal to new areas with suitable climatic conditions and conversely, assuming unlimited dispersal into new suitable

areas. The actual responses of species will likely fall between these two extremes. For the assumption of no dispersal, we calculated "species loss" for a cell as the percentage of all modeled species currently occurring in the cell whose predicted future range did not include the cell. Under the assumption of unlimited dispersal, we calculated "species gains" and "species turnover". Species gains were calculated as the number of species not in the cell whose future range did include the cell. Like losses, gains were expressed as a percentage of the number of species currently in a cell. Species turnover is a composite measure of both potential species losses and potential species gains and was calculated as 100*((number of species lost from a cell + number of species gained by a cell) / current number of species).

We summarized the 10 predictions of species loss, gain, and turnover for each greenhouse-gas emissions scenario by taking the 20th percentile (80% of the models predicted at least that much change) of the distribution of loss, gain, and turnover values for each grid cell. These values were used to identify areas in which 80% or more (at least 8 out of 10) of the climate projections for each greenhouse-gas emissions scenario predicted high species loss, gain, and turnover.

Findings

Under all three greenhouse-gas emissions scenarios, most of the United States is predicted to experience significant changes in animal communities. Eighty percent of the analyzed climate-change projections predict at least 10-20% species loss over roughly half of the United States under the lower B1 emissions scenario and at least 10-20% loss over most of the United States under the mid-high A2 scenario (Figure 1). Under the A2 scenario, eighty percent of the climate projections result in at least 20-30% species loss for many areas in the central and southwestern United States. In addition, several areas in Central and South America are consistently projected to experience large losses. Eighty percent of the analyzed climate-change projections predict at least 20-30% species loss under the lower B1 emissions scenarios, and at least 50-60% loss under the mid-high A2 scenario in parts of Vera Cruz, the Yucatan Peninsula, and the Andes Mountains.

Several areas are predicted to gain substantial numbers of species as a result of range shifts and expansions (Figure 2). Percentage wise, the largest gains in species are predicted for the northern latitudes and the Andes mountains, where even under the lower B1 emissions scenario, eighty percent of the climate simulations result in at least 60-70% species gains. When losses and gains are both taken into account, the models predict relatively large changes across much of the western hemisphere (Figure 3). Large portions of both North and South America are projected to experience at least 20-30% species turnover for eighty percent of the climate projections under all three greenhouse-gas emissions scenarios and at least 30-40% species turnover under the mid-high A2 scenario. Parts of the Andes, Central America, and the far northern boreal forests and tundra are predicted to experience greater than 80% species turnover, which would mean that the vertebrate communities in those regions would bear almost no resemblance to today's fauna. Due to latitudinal trends in species richness, the largest changes in the absolute number of species are predicted for the tropics. For the tropics, the maximum projected changes in the numbers of species across scenarios are 352 and 465 species, for no-dispersal and full-dispersal scenarios, respectively.

There are several reasons why these analyses provide a conservative estimate of the future climate-driven changes in biodiversity. First, because the approach we used does not directly model interactions between species, it is likely that shifts in the ranges of other species and particularly in the distribution of diseases and pathogens (Pounds et al. 2006) will further alter ecological communities. Second, our models also do not account for land-use change, which could cause many species to disappear from a region or prevent them from occupying newly created suitable climates. Third, we only include in our analyses those species for which we were able to build models that accurately predicted current ranges. Although this restriction improved the accuracy of our analyses over those in previous studies, it generally biased us towards including species with larger, more contiguous ranges. Many of the species that were not modeled had small or highly fragmented ranges. These species are likely to be more susceptible to climate-induced range loss and range contraction due to their restrictive habitat requirements. Thus, our estimates of potential faunal change would likely be much greater if these species could have been modeled. Finally, we have modeled changes in species ranges as defined strictly by changes in climate. Climate change is also likely to alter habitat by changing sea level (Meehl et al. 2005, Alley et al. 2007), fire regimes (Westerling et al. 2006), as well as hydrological and other disturbance regimes.

Conclusions

The results of our study indicate that large portions of North and South America are likely to experience major climate-induced changes in animal assemblages in the coming century. Eighty percent of the climate-change scenarios we investigated resulted in species turnover rates of at least 20-30% for much of North and South America under even the lower B1 greenhouse-gas emission scenario and at least 30-40% under the mid-high A2 scenario. These are likely to be conservative estimates of change because 1) they do not include many vertebrate species with small or fragmented ranges, 2) they do not account for interactions between species, and 3) they do not take into account many of the other climate-induced factors such as changing disturbance regimes and disease frequency and prevalence that will alter species distributions and animal communities.

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Table 1. Atmosphere-ocean general circulation models from which projections were obtained.

Model Name	Model Vintage	Modeling Group	References
CGCM3.1 (T47)	2005	Canadian Centre for Climate Modeling & Analysis, Canada	(McFarlane et al. 1992, Flato 2005)
CNRM-CM3	2004	Météo-France/Centre National de Recherches Météorologiques, France	(Déqué et al. 1994, Terray et al. 1998)
GFDL-CM2.0	2005	Geophysical Fluid Dynamics Laboratory, USA	(Delworth et al. 2006)
GFDL-CM2.1	2005	Geophysical Fluid Dynamics Laboratory, USA	(Delworth et al. 2006)
GISS-ER	2004	NASA/Goddard Institute for Space Studies, USA	(Schmidt et al. 2006)
INM-CM3.0	2004	Institute for Numerical Mathematics, Russia	(Diansky and Volodin 2002, Galin et al. 2003)
MIROC3.2(medres)	2004	Center for Climate Research, Japan	(K-1 Developers 2004)
MRI-CGCM2.3.2a	2003	Meteorological Research Institute, Japan	(Shibata et al. 1999, Yukimoto and Noda 2003)
CCSM3.0	2005	National Center for Atmospheric Research, USA	(Collins et al. 2006a, Collins et al. 2006b)
UKMO-HadCM3	1997	Hadley Centre for Climate Prediction and Research/Met Office, UK	(Gordon et al. 2000, Pope et al. 2000)

Figure 1. Consistent predictions of climate-induced species range losses for lower B1, mid A1B, and mid-high A2 greenhouse-gas emissions scenarios. Each map was created using predictions of faunal change based on 10 different climate-change projections. Species-loss values assume no dispersal of individuals to newly created suitable climatic environments. Eighty percent of the climate projections (8 of the 10) resulted in losses greater than the values represented in the maps.

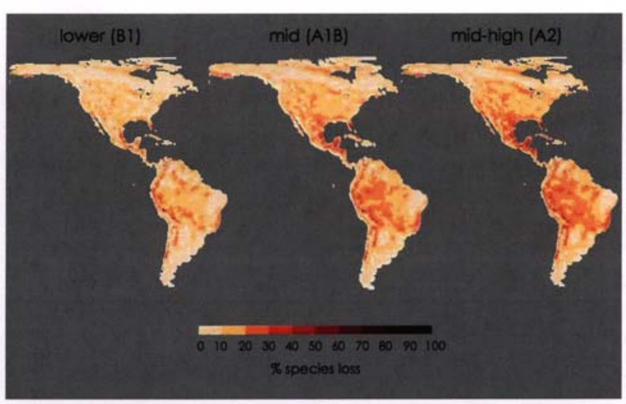


Figure 2. Consistent predictions of climate-induced species gains for lower B1, mid A1B, and mid-high A2 greenhouse-gas emissions scenarios. Each map was created using predictions of faunal change based on 10 different climate-change projections. Eighty percent of the climate projections (8 of the 10) resulted in percent gains greater than the values represented in the maps.

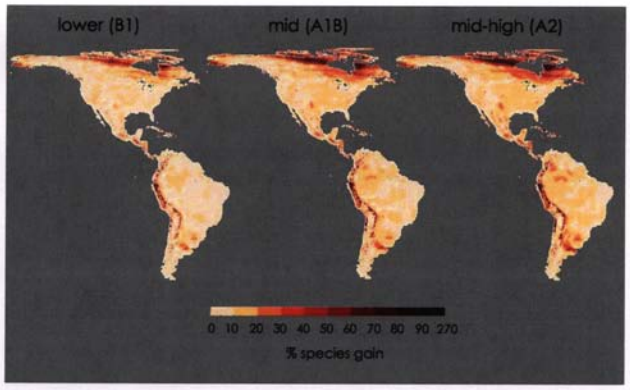
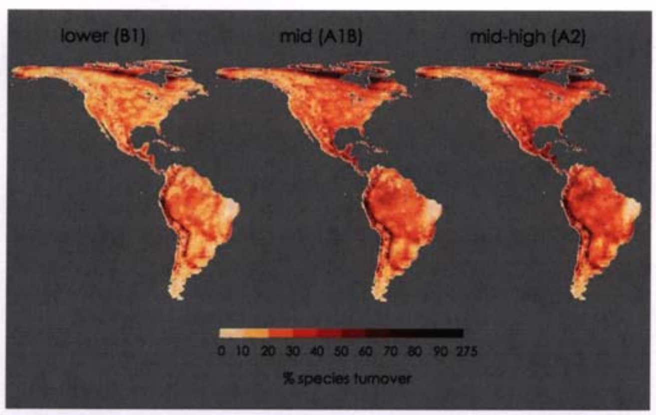


Figure 3. Consistent predictions of climate-induced species turnover for lower B1, mid A1B, and mid-high A2 greenhouse-gas emissions scenarios. Each map was created using predictions of faunal change based on 10 different climate-change projections. Eighty percent of the climate projections (8 of the 10) resulted in percent turnover values greater than the values represented in the maps.



Response to questions submitted for the record by Dr. Josh Lawler

QUESTIONS FROM THE HONORABLE MADELEINE BORDALLO, CHAIRWOMAN

Your research predicting that most of the United States will experience serious changes in animal communities is alarming. I was particularly impressed by your prediction that in parts of the Andes Mountains, Central America and the far northern boreal forest and tundra regions future wildlife communities will bear almost no resemblance to wildlife there today?

1. Is there any scientific evidence indicating that similar kinds of changes in species distribution have occurred within the same time frame predicted by the different scenarios in your research? Has the earth ever experienced something like this before?

Our models predict changes in wildlife communities over a 100-year period. Although the plants and animals of specific locations have changed dramatically in the past, these major changes generally have occurred over much longer time periods. However, it is impossible to know for certain because rapid changes cannot be detected by studying the fossil record. Rapid historic changes are known, but these can be clearly linked to human activities such hunting, land-use change, or the introduction of non-native predators. Examples of these changes include the extinction of the Australian and the North American megafauna. Regardless of whether similar changes have occurred in the past, the fish and wildlife of today will have more trouble responding to climate change. Because we have so dramatically altered the landscape and native habitats, species will have trouble moving in response to climate change and in many cases, there will be little undisturbed habitat into which to move.

2. You note that a shifting climate will alter the spread of diseases and pathogens which will further disrupt ecological communities, and additionally, that human land-use changes will further stress wildlife. Does this argue for the need to develop a more holistic land planning strategy that up front accounts for the needs of wildlife?

Yes, the ecological changes set in motion by climate change will require new ways of approaching conservation and land management. To protect wildlife, it will be necessary to make management decisions at much larger spatial scales. It will require close cooperation across federal lands and federal agencies to organize both management strategies and land acquisitions. I have provided some more specific recommendations in my responses to Representative Kennedy s comments below.

QUESTIONS FROM THE HONORABLE DALE KILDEE

The recent IPCC report concludes that rising sea levels will have negative consequences for wildlife and that essential wildlife habitats in low-lying coastal areas may be at serious risk. Yet, I am concerned about an opposite effect that reduced precipitation and longer droughts brought about by a warming climate might cause the water levels of the Great Lakes to drop dramatically. This would have disastrous effects on the Great Lakes themselves and on the economies and communities that depend on, or lay along, the lakefronts.

1. Under the various climate change models used to make predictions about future conditions, can you tell me what is projected for the Great Lakes? Will lake levels rise or fall? What can we expect to see in changes to the composition, distribution and abundance of wildlife and aquatic species?

The Great Lakes are already changing in response to climate change and are expected to change more dramatically in the coming century (UCS and ESA 2005). The levels of the Great Lakes are predicted to decrease in response to evaporation from increasing temperatures and the concurrent lack of significant increase in precipitation. Reduced ice cover and increased frequency of heavy precipitation events and droughts are also predicted. Predicted increases in lake temperatures and loss of ice cover will likely result in reduced whitefish production in the lakes. In the Great Lakes region as a whole, increased water temperatures will mean reductions in lake trout, brook trout, walleye, and northern pike populations and potential increases in bluegill and smallmouth bass populations. Aquatic communities will be further changed as exotic species such as the common carp and native species to

the south move into the Great Lakes region. Finally, longer periods of summer stratification may lead to increased oxygen depletion resulting in the formation of deep-water dead zones in some areas.

Union of Concerned Scientists and Ecological Society of America. 2005. Confronting Climate change in the Great Lakes Region.

QUESTIONS FROM THE HONORABLE PATRICK KENNEDY

Regardless of whether or not we take actions to control and reduce green house gas emissions, wildlife and wildlife habitat and the ocean environment are going to change and adapt, often unpredictably, to a warming climate. Consequently, we should take steps now to develop strategies to allow for the future conservation of biodiversity and the maintenance of a healthy and resilient environment.

2. Keeping in mind that any transition to a new Green Economy will take decades to achieve and that most Members of Congress will want to limit unnecessary disruptions of social and economic systems, can you be more specific on what practical types of adaptive management strategies we should consider to mitigate the negative effects of climate change on our collective wildlife and ocean resources?

There are several strategies that agencies can begin to adopt to address climate change. Below I list some of the more general strategies and a small sample of some of the more specific strategies that can be undertaken in specific ecological systems.

General strategies:

1. Increase connectivity between protected lands (national parks, wildlife refuges, national forests, etc.) to allow species to move more easily in response to climate change.
2. Better coordinate management across protected lands within and between agencies.
3. Adopt adaptive management practices. The term adaptive management has a specific meaning in the ecological literature. The concept has been around quite a while and is not necessarily specific to addressing climate change. Adaptive management involves conducting management experiments and then altering management strategies based on the outcome of those experiments. It requires closely monitoring a system and potentially changing management approaches several times.
4. Monitor species and systems that are likely to be most sensitive to climate change. Some of the agencies (e.g., NPS) currently have monitoring programs in place, but others do not. These programs need to be expanded and they should target specific climate-sensitive species or systems.
5. Augment the current system of protected lands with additional lands that will protect species as systems change and species move. In some cases we have a good idea of where these lands will need to be, but in other cases, we do not. For example, as sea level rises, many estuaries and tidal marshes will be inundated. Entire wildlife refuges along the southeastern coast of the U.S. may be lost to rising sea levels. One strategy to provide habitat for the species in these refuges will be to secure land that is inland and adjacent to these refuges.
6. Educate land managers about the potential effects of climate change and distribute tools and techniques for addressing the changes they are likely to see.
7. Closely monitor for new invasive species that may move on to protected lands in response to climate change. Also, develop strategies for removing or containing new invasive species when they arrive.

Examples of specific management practices:

1. Translocations may be necessary to preserve some plant and animal species that will lose substantial amounts of habitat as the climate changes.
2. Stream bank stabilization may be useful in areas that will see changes in flow regimes.
3. Restoring riparian vegetation for some streams may help reduce stream temperatures by shading.
4. In some cases, it may be most efficient to stop managing for the habitat of a species at the trailing edge of its current range and to transfer those management efforts to another area that is more likely to still provide suitable habitat or suitable climatic conditions in the future.
5. Dam removal may be necessary to allow cold-water fish to move upstream to cooler waters in response to increasing stream temperatures.

2. Should we be doing more to re-evaluate our current policies for land use planning and public acquisition of land for wildlife habitat? Should we be adopting a broader landscape and ecosystem-based approach for protecting wildlife?

Yes, land-use planning and land acquisition for wildlife should be done with the potential effects of climate change in mind. It may be possible to acquire lands that will provide needed habitat for a species that is forced to move out of a current protected area. New land acquisitions may also be used to help connect current lands to allow species to move more successfully from one protected area to another as the climate changes.

3. Finally, how might such ideas be applied to the ocean and coastal environment and the wildlife therein?

There are several things that can be done to begin to implement management strategies aimed at addressing climate change. First, I suggest establishing an interagency council that advises all federal agencies on climate change issues. The council would disseminate information, and coordinate research, monitoring, and land acquisition. Second, I suggest establishing a central data repository where federal scientists and managers can access the latest climate-change related data and studies. Finally, the agencies charged with managing wildlife or wildlife habitat will need substantial increases in their budgets to 1) design and implement adaptive management experiments (see my definition of adaptive management above), 2) develop and implement extensive, targeted monitoring programs, 3) hire new staff with new skills and knowledge, 4) run models to assess the potential impacts of climate change (e.g., hydrological models, fire models, vegetation models, species distribution models), and 5) conduct regional training and planning workshops.

QUESTIONS FROM THE HONORABLE HENRY BROWN, MINORITY RANKING MEMBER

1. When you reference your research you are mainly referring to modeling various scenarios to project different outcomes on animals, correct? While computer models have become more sophisticated over the years they are not perfect predictors, correct?

The projected changes in animal distributions I have discussed are the results of modeling studies. No model is ever a perfect representation of reality, nor do models always produce perfect predictions. Nonetheless, models are incredibly useful tools. The general type of model used in our study is also used in medical research. For example, we rely on such models to predict disease risks.

2. You make reference to using models that have accurately predicted current ranges. My understanding is that this type of model could lead to more accurate models of projected changes for the future. However, we are still talking about predictions and projections. Do you agree that there could be variables that are not accounted for that could change the projected outcome?

There is no guarantee that a prediction or projection from a model or an expert will come to fruition. This is true for any field, whether it be military strategy, economics, medicine, meteorology, or biology. Without predictions and projections, however, we would be extremely limited in our ability to plan for the future. The models used in our study use a comprehensive set of bioclimatic variables. Nonetheless, there are certain ecological relationships that are not directly modeled in our analyses. If these processes were directly modeled, it might change our projections for individual species and potentially our overall projections of local species loss and turnover. However, our models produce conservative estimates because they don t account for many of these other factors. If we were to take some of these other ecological factors were taken into account, it is likely that our estimates of turnover would be higher.

3. What do you mean when you say species turnover? Is this code for species extinction or does it refer more to species movement?

In the context of my analyses, species turnover refers to the change in local species composition, not to extinctions. There is more uncertainty involved with predicting extinctions and thus I have chosen to predict changes due to predicted range contractions and expansions instead. Many of the species predicted to be lost from one area are predicted to potentially be able to inhabit other, new areas. The ability of species to move into these areas will, however, be limited by their dispersal abilities and by the types of landscapes they have to move through.

4. A key to models accurately predicting future climate changes or species movement is for the model to accurately predict past changes. Have any of your models accurately produced past range-shifts in species?

I have not tested my models using historic distribution data, largely because these data do not exist for most of the species in mystudy. There are several ways to test a model. The best way is to use a completely independent data set. These data generally have to be from a different location or from a different time period. Unfortunately even data from the past are not completely independent as they are temporally correlated. Nonetheless, testing a model by predicting past distributions is likely to provide a better assessment of model accuracy than testing a model using less independent data sources. It is important to note, however, that accurately predicting past trends does not assure that a model will accurately predict future trends.

5. In your written testimony you discuss species niche modeling. A recent article in the scientific journal of Bioscience (March 2007 Vol. 57 No. 3) states that niche-theory models are difficult to validate. The article references one of your works of species niche modeling, specifically Lawler, et al. 2006, stating that six approaches to modeling the effects of global warming on fauna were compared; however, the models were not independently validated. It goes on to say that the inherent variability of niche modeling can overestimate the probability of extinction. How can we trust your modeling techniques over other model predictions if they were not independently validated?

Validating predictions of future conditions provides a unique challenge. Ideally, bioclimatic models should be tested with completely independent datasets. One option is to use data that is from outside the study region. When modelling large spatial extents, these independent datasets are difficult to obtain. Many species are limited to a single continent or a single hemisphere, and those that are more widely distributed often occur as invasive or exotic species and hence their new ranges are rarely fully realized. An alternative approach is to use historic data to test model projections. Historic data are likewise only available for a few species in specific locations.

Our models have been validated with a semi-independent dataset. In this study, we used a method of model validation that has been called data splitting (Araújo et al. 2005). It is a semi-independent form of validation in which a portion of the dataset is reserved before model building and set aside for model testing. Due to spatial autocorrelation, this approach does not provide truly independent model validation. Fortunately, there is evidence that model assessments based on semi-independent data-splitting approaches can provide results that are similar to those attained using more independent data sources. Araújo et al. (2005) found that model assessments using a data-splitting approach provided more optimistic estimates of model performance than did assessments using more independent, historic data sets. However, for the best performing niche-modelling approaches, the differences in performance based on the two assessments were relatively small. Furthermore, for the 116 bird species used in the study performed by Araújo et al., there were moderate to strong correlations between the accuracy values produced by the more and less independent assessments, particularly for the more accurate modelling approaches. Thus, the models that performed best when tested with the semi-independent reserved data set were also generally the models that performed best when tested on the more independent historic data set.

It is true that the uncertainty in niche modeling can lead to over estimates of extinctions. It can likewise lead to underestimates of extinctions. We, however, did not attempt to estimate extinction rates precisely because there are more uncertainties involved with such estimates than with the estimates of future local loss and turnover that we have produced.

Araújo, M. B., Pearson, R. G., Thuiller, W. & Erhard, M. Validation of species climate impact models under climate change. Global Change Biol. 11, 1504-1513 (2005).

6. How accurate is the Intergovernmental Panel on Climate Change statement that 20 to 30 percent of plant and animal species are at risk of extinction?

The IPCC (2007) report cited published research from Thomas et al. (2004). Although we cannot test these predictions and thus cannot provide an estimate of their accuracy, we have already begun to see extinctions that can be attributed to recent climate change. For example, climate change has caused the extinction of 75 amphibian species in Costa Rica (Pounds et al. 2006). Because the predicted future

changes in climate are far great than the changes we have witnessed in the past 100 years, we can expect even more climate-driven extinctions in the future.

Intergovernmental Panel on Climate Change (IPCC). 2007. Climate Change 2007: Impacts, Adaptation, and Vulnerability. Cambridge University Press, Cambridge, UK.

Pounds, J.A., M.R. Bustamante, L.A. Coloma, J.A. Consuegra, M.P.L. Fogden, P.N. Foster, E. La Marca, K.L. Masters, A. Merino-Viteri, R. Puschendorf, S.R. Ron, G.A. Sanchez-Azofeifa, C.J. Still, and B.E. Young. 2006. Widespread amphibian extinctions from epidemic disease driven by global warming. Nature 439: 161-167.

Thomas C.D., A. Cameron, R.E. Green, M. Bakkenes, L.J. Beaumont, Y.C. Collingham, B.F. Erasmus, M.F. De Siqueira, A. Grainger, L. Hannah, L. Hughes, B. Huntley, A.S. Van Jaarsveld, G.F. Midgley, L. Miles, M.A. Ortega-Huerta, A.T. Peterson, O.L. Phillips, and S.E. Williams. 2004. Extinction risk from climate change. Nature 427: 145-148.

7. One could say we are experiencing an extended drought with a number of related impacts; increased insect and disease levels, higher tree mortality, more and larger fires, etc. Perhaps that drought is the result of global warming or perhaps not. Can you, Dr. Lawler, tell the difference?

It is not possible to tell whether any one weather event is the result of climate change. However, it is possible to link trends with predicted changes in climate. We are starting to see trends in fire size and severity, the variability in precipitation and temperature, and extreme temperature events, that are consistent with predicted changes in climate.

8. Also, over the millennium, climate change has affected forests dramatically—-tropical forest fossil exist under glaciers today. What is different now from those previous climate changes in regards to plant succession (long before human influence)—-were those changes good or bad?—-and why are they considered good or bad today?

The main difference between past climate-driven vegetation shifts and those that are likely to result from predicted future climatic changes is that the changes in the past have occurred over much longer time periods. We are expecting to see dramatic changes in plant and animal distributions in the coming century as opposed to changes over thousands to millions of years. Another difference is that landscapes of today are fragmented by agriculture and development. In the past, species could much more freely move across continents in response to climate change. Because we have so dramatically altered landscapes and native habitats, species will have trouble moving in response to climate change and, in many cases, there will be little undisturbed habitat into which to move.

Changes in climate or species distributions are, of course, only good or bad from a particular perspective. There will be negative economic effects from lost coastal property, increased storm and flood damage, drought impacts, insect infestations, and new weeds and other crop pests. There may be economic benefits in some areas in which agricultural production benefits from increased temperatures or increased precipitation. With respect to wildlife, those that value biological diversity, ecosystem services (such as clean water, hunting, seafood), and wildlife in general, will see the predicted impacts on ecological systems as negative.

9. What has happened to plant species mix in previous warming cycles? And what happens to species mix and plant succession? What do fossil records show?

Pollen records indicate that warm periods and glacial periods caused vegetation to shift latitudinally across vast parts of the globe. For North America, see Davis and Shaw (2001).

Davis, M.B. and R.G. Shaw. 2001. Range shifts and adaptive responses to Quaternary climate change. Science 292: 673-679.

10. Is the statement by the current issue of Newsweek accurate that Coal is the cheapest and dirtiest source of energy around. If we cannot get a handle on the coal problem, nothing else matters?

This question is outside the realm of my expertise.

11. How accurate are the computer modeling techniques used to by the Intergovernmental Panel on Climate Change (IPCC) to predict the earth s climate change? What specific climate changes were accurately predicted by the IPCC models or other climate computer models?

There is a high level of confidence in the projections of the general circulation models used in the IPCC reports. These models are based on accepted physical prin-

ciples and the models have been well refined over time. The models do a good job of correctly predicting past climatic events. For example, they simulated the warming of the mid-Holocene and the last glacial maximum. The also correctly capture more recent events such as cooling resulting from four major volcanic eruptions in the 20th century (Satna Maria, Agung, El Chichon, and Pinatubo). For a more comprehensive review please see Randall et al. (2007).

Randall, D.A., R.A. Wood, S. Bony, R. Colman, T. Fichefet, J. Fyfe, V. Kattsov, A. Pitman, J. Shukla, J. Srinivasan, R.J. Stouffer, A. Sumi, and K.E. Taylor. 2007. Climate Models and Their Evaluation. In Intergovernmental Panel on Climate Change (IPCC). 2007a. Climate Change 2007: The Physical Science Basis. Cambridge University Press, Cambridge, UK.

12. Some scientists believe that changing land use practices have actually increased the carbon absorption of Northern Hemisphere forests. Can additional actions be taken to increase terrestrial carbon sequestration?

This question is somewhat outside of my realm of expertise, I refer you to the IPCC report on mitigation (IPCC 2007).

Intergovernmental Panel on Climate Change (IPCC). 2007. Climate Change 2007: Mitigation. Cambridge University Press, Cambridge, UK.

13. How promising are the artificial carbon sequestration techniques which would capture carbon dioxide and inject it deep into the ocean or in declining oil fields, saline aquifers, or unminable coal seams?

This question is outside the realm of my expertise.

14. Do you or have you (or your organization) received any funding from the Pew Charitable Trust or the David and Lucille Packard Foundation? If so, please elaborate.

I have not received any funding from either the Pew Charitable Trust or the David and Lucille Packard Foundation.

15. Are you currently a party to any law suit against the Department of the Interior or the Department of Commerce (or any of the agencies within these departments)? If so, please describe.

I am not currently involved in any lawsuits.

QUESTIONS FROM THE HONORABLE WAYNE GILCHREST

1. If paleo-records show that corals existed in the past under high atmospheric CO_2 concentrations, why is it a problem now?

This question is outside my realm of expertise.

2. Among the various effects of climate change to wildlife and the oceans, are there issues that are more pressing than the others? Why?

There are definitely some systems and some species that are at higher risk of being adversely affected by climate change than are others. For example, low-lying coastal areas, particularly coastal marshes will be highly susceptible to loss and change driven by rising sea levels. High elevation, alpine habitats will be lost as temperatures rise and tree lines continue to move upward. Precipitation-fed wetlands will be particularly vulnerable to increased evaporation driven by increased temperatures. Wetlands and ponds in Alaska are already drying and draining due to melting permafrost. The fish and wildlife species in these and other highly sensitive habitats will often be the first to be affected by climate change. To protect these species, it may be necessary to first concentrate our efforts on the most sensitive systems, keeping in mind that it will be difficult, if not impossible, to address change in some systems.

3. In the U.S., as plant and animal species migrate north and to higher elevations, what does that mean for the regions they leave behind? For instance, it has been said that some U.S. states that border Canada might actually benefit from the next few decades of climate change, but what will it mean for the states further to the South, and especially those on the coast?

Some areas will likely see an influx of species as species move in response to climate change. High elevations and the high latitudes will likely be colonized by new species. These new additions have the potential to greatly change the systems into which they move. The southern states are particularly vulnerable to invasion by species that have not yet been seen in the U.S. that will move north from Central and South America. Some of these species will potentially be crop pests or weeds.

Because we have not had them in the U.S. before, we will not have established methods for dealing with them. At the northern border with Canada, climate change will likely drive some species over the boarder meaning that some of our natural heritage and wildlife resources will be lost to the north.

4. How do shifts in habitat range of plants and animals affect human interests such as agriculture or the spread of invasive species and diseases? How can we adaptively plan for such changes?

As species move in response to climate change, there will be new invasive species, new crop pests and pathogens, and new disease introduced both locally and nationally as species move to new states and into the U.S. from Central and South America. We have already seen shifts in the distributions of some forest pests such as the mountain pine beetle (Logan et al. 2001). Continued increases in winter temperatures may allow the beetle to spread across northern Canada and down into the eastern U.S. If this spread occurs, pine forests in the east that have not historically been exposed to this beetle will be vulnerable to attack.

The best way to reduce new invasions is to reduce greenhouse-gas emissions. However, given that we are already committed to significant future changes in climate, it will be necessary to develop other methods for addressing moving pests, pathogens, and diseases. Because it is often most feasible to address pests and diseases when they are in low abundance, it is necessary to detect invasive species and new diseases as early as possible. Early detection will require predictive modeling and targeted monitoring. The modeling can be used to determine which areas of the country will be most susceptible to which pests and diseases and the monitoring can be used to detect when and if those organisms arrive in an area. Modeling can also help predict which new diseases and pathogens might move into the U.S. from South and Central America. We can then begin to adopt and develop eradication or control measures for these species before they arrive.

Logan, J. A., and J. A. Powell. 2001. Ghost forests, global warming, and the mountain pine beetle (Coleoptera: Scolytidae). American Entomologist 47:160-167.

5. The IPCC reports with 80% certainty that the changes in water temperatures, ice cover, salinity and ocean circulation are impacting the ranges and migration patterns of aquatic organisms. How will this affect management and use of these resources, and how can we prepare for any changes?

This question is outside the realm of my expertise.

6. In the Chesapeake Bay, we are losing marshland to rising sea levels. Can you talk about what is happening to coastal wetland areas in other areas of the country and what that is doing to their ecosystems and the local economies that depend upon these natural resources?

Along the mid-Atlantic coast, the highest rate of wetland loss is indeed in the center of the Chesapeake Bay region of Maryland. The Blackwater National Wildlife Refuge has lost 7,907 acres of marsh over the past 60 years (approximately 130 acres per year). Models predict that in 50 years continued sea-level rise in conjunction with global climate change will completely inundate existing marshes (Larsen et al., 2004). Substantial loss of wetlands and marshes is also occurring along the Gulf Coast. In Louisiana, sea-level rise in conjunction with high rates of subsidence, economic growth, and hurricanes has contributed to an annual loss of nearly 25,000 acres of wetlands, even prior to Hurricane Katrina (Erwin et al., 2004). The southeast coast is another region that is particularly susceptible to the loss of wetlands and marshes due to sea-level rise.

The National Wildlife Refuge System is particularly threatened by sea-level rise as many of the refuges are on low-lying coastal marshes, estuaries, or wetlands. Some of the most vulnerable refuges include the Chincoteague National Wildlife Refuge, on the Delmarva Peninsula, the Alligator River National Wildlife Refuge on the Albemarle Peninsula of North Carolina, and the Merritt Island National Wildlife Refuge in Florida. In fact, many of the refuges in New England, the Middle Atlantic states, North Carolina, and Florida are coastal and susceptible to sea-level rise. For many of these refuges, seal-level rise will drastically alter habitat by inundating estuaries and marshes and converting forests to marshes. Beach-nesting birds such as the Piping Plover, migratory birds using the refuges as stopovers, and species using low-lying habitats such as the red wolf and Florida panther will likely lose habitat to sea-level rise (Schyler 2006).

Loss of coastal marshes and wetlands will have substantial impacts on fishing and particularly shellfish harvesting economies. These wetlands act as nurseries for many marine species, not just those that are harvested from the marshes them-

selves. These impacts will likely affect coastal communities in the Mid-Atlantic states, the southeastern U.S., and the gulf states the hardest.

Erwin, R. M., G. M. Sanders, and D. J. Prosser, 2004: Changes in lagoonal marsh morphology at selected northeastern Atlantic coast sites of significance to migratory waterbirds. Wetlands, 24(4), 891-903.

Larsen, C., I. Clark, G. Guntenspergen, D. Cahoon, V. Caruso, C. Hupp, and T. Yanosky, 2004: The Blackwater NWR Inundation Model. Rising Sea Level on a Low-lying Coast: Land Use Planning for Wetlands. U.S. Geological Survey, Reston, VA.

Schlyer, K., 2006: Refuges at Risk, the Threat of Global Warming. Defenders of Wildlife, Washington, D.C.

7. What role do marshlands play in sequestering carbon? Is marsh restoration a viable alternative in carbon sequestration?

Although this is not my area of expertise, I can provide a quick answer. Wetlands contain 10% of the carbon contained in all the plants and soil of the world (IPCC 2001), mainly in soil. However, wetlands also emit approximately 20% of all methane, a greenhouse gas more potent than carbon dioxide, from human and natural sources (IPCC 2007). Thus, they also contribute to greenhouse-gas emissions. In some areas (temperate and tropical areas) the effect of carbon sequestration is predicted to be larger than the effect of methane emissions. Thus, the conservation and restoration of marshes can sequester globally significant amount of carbon and help attenuate climate change in the much of the U.S.

Intergovernmental Panel on Climate Change (IPCC). 2001. Climate Change 2001: The Scientific Basis. Cambridge University Press, Cambridge, UK.

Intergovernmental Panel on Climate Change (IPCC). 2007. Climate Change 2007: The Physical Science Basis. Cambridge University Press, Cambridge, UK.

8. The latest IPCC report warns that ocean acidification poses a threat to coral reefs and shell-forming organisms that form the base of the aquatic food chain. But the report says more study is needed to determine the full scope of the threat. What do we know about the potential impacts to U.S. coastal ecosystems today and how quickly is our understanding of acidification improving? What can Congress do to improve upon this understanding? Do we know enough to act?

This question is outside my realm of expertise.

9. What additional resources or tools will the Fish and Wildlife Service and National Marine Fisheries Service need to adequately prepare and address the impacts of global warming on wildlife over the next decade?

Both the FWS and NMFS will need additional resources to address the impacts of climate change. I have provided a list of some of the general and more specific tools and strategies that will be needed in my responses to Representative Kennedy above.

10. We ve heard a lot about the polar bear and the petition to list the species under the Endangered Species Act (ESA). Opponents of listing claim that the effects of global warming are in fact unclear. What evidence is there that global warming is already having a dramatic effect on the species across its range? How will an ESA listing help polar bears?

The major threat to the polar bear is the loss of sea-ice habitat due to increasing temperatures. Loss of sea ice means that the bears spend more time on land and are unable to hunt seals and other high quality prey items. There have been clear losses in sea-ice cover and these losses can be linked to changes in polar bear distributions, reductions in polar bear body condition, reproductive rates, and cub survival. The loss of sea ice means that some bears have been stranded on flows and are unable to get back to their primary habitat. Others have been seen swimming long distances to reach sea ice. More information on the listing can be found at: http://alaska.fws.gov/fisheries/mmm/polarbear/pdf/Polarbear__proposed__rule.pdf

The listing of the polar will reduce some of the other stresses, such as harvest, on polar bear populations. The fact that polar bears will be spending more time on land will likely mean there will be more interactions with humans. An ESA listing will help protect the bears in these cases.

Ms. BORDALLO. Thank you very much, Dr. Lawler.

I now recognize Dr. Terry Root to testify for five minutes.

STATEMENT OF TERRY ROOT, Ph.D., CENTER FOR ENVIRONMENTAL SCIENCE AND POLICY, STANFORD UNIVERSITY

Dr. ROOT. Madam Chairwoman and Members of the Subcommittee, I am Terry Root from Stanford University, and I also am a lead author in previous IPCC works, the Intergovernmental Panel for Climate Change, and the one that was just released on April 6.

Now, the globe is warming at an escalating rate. Plants and animals on all continents are already exhibiting four different types of changes. These include, first, species extending their range boundaries north in the U.S. and up in elevation; second, species shifting the timing of various spring events; the third is a lot of different kind of small studies that have been done, so it is kind of a catchall group; and fourth is local or global extinction.

Now what I would like to do is go through three of these changes in more detail. First is the change in ranges. The movement of species forced by rapidly rising temperatures are frequently slowed and often blocked by other human-made stresses like land use change. This means individuals moving north or up in elevation have to navigate around, over or across freeways, agricultural area, industries parks and cities.

Additionally, species have been found to move at different rates and directions. Such independent shifting will most likely result in a tearing apart of communities, natural communities, thereby disturbing biotic interactions such as predator/prey relationships.

The second type of change is a change in timing. Species are already shifting the timing of various events occurring in the spring, such as frogs breeding earlier or the cherry blossoms that are blooming here in Washington, D.C.

Over the last 30 to 40 years, around 115 species that I was able to find in the literature, and this is plants and animals together; these are from locations around the globe, were found to be changing the timing of a spring event earlier by about five days per decade, so that is 15 days over the 30 years that they have already changed.

I would like to talk about the last, which is the local and global extinctions. This can occur when species cannot move as the temperature increases due to either lack of available habitat or the inability to access it. These species are called functionally extinct because without human assistance the probability of extinction is quite high.

The money, land, personnel and political will are just not available right now for such endeavors. Consequently, many scientists predict that we are standing at the brink of a mass extinction that would be caused by one very careless species.

Roughly 20 to 30 percent of species assessed thus far are likely to be at an increasingly high risk of extinction if the global mean temperature exceeds two to three degrees C above preindustrial, and that is just 1.3 to 2.3 degrees C above what we are right now.

Given that there are around 1.7 million identified species on the globe, somewhere between 340,000 and 570,000 species could actually go extinct primarily due to our negligence.

The need for species to move as temperatures increase could cause wildlife managers to face a number of novel challenges over

the next several decades. An adaptation strategy for managers is to reduce and manage other stresses such as habitat fragmentation and pollution and the like.

To date, preservation practices infrequently address rapid climate change. Effective adaptive responses are likely to be costly to implement, but nonimplementation could easily cost more through both dollars and in species.

Species currently protected on national lands could easily move to less protected lands that may not be conducive to protecting the species anymore. Reliable forecasting of possible responses of species can be invaluable to managers because then appropriate management practices may be designed proactively.

Thank you.

[The prepared statement of Dr. Root follows:]

Statement of Terry L. Root, Senior Fellow—University Faculty, Stanford University

Over the last 100 years, the average global surface temperature has warmed approximately 0.7oC (1.4oF) and is projected to rise at an increasing rate over the next century. This rate of warming is significantly larger than the rate of sustained global warming over the 6,000 years or so that it took for the globe to warm about 6oC from the last ice age to our current warm interglacial period. That temperature transition, which occurred about 12,000 to 18,000 years ago, represented a warming rate of about 1oC (1.8oF) per thousand years. Extrapolating out the more recent warming trend to a comparable 1000 years, we see that a 7oC/1000 years raise in temperature is some 7 times faster than in the last 18,000 years. As the planet continues to warm, the rate will continue to escalate.

A primary concern about wild species and their ecosystems is currently they are not only having to adapt to warm temperatures, but they are also having to cope with the most rapid rate of temperature increase in the last 18,000 years. Additionally, in the pre-historic past, plants and animals were not under stressed due to other human-caused problems: pollution, land-use change, invasive species, and others. Today the synergistic effects of these stresses combined with rapid warming are greatly influencing the resilience (ability to return to the same condition after a stress) of many species, communities and ecosystems. What is concerning is that very noticeable changes have been measured in species over the last 30 to 40 years during which the global temperature increased around 0.5oC. Yet, the Summary for Policy Makers of Working Group I of the Fourth Assessment Report of the IPCC explained that the global temperature could rise as much as 6.4oC and even beyond if we stay on the energy path we are currently traveling. It is highly likely that all but a few species and ecosystems will be able to adapt to that amount of temperature change.

By 2100 the resilience of many ecosystems is likely to be exceeded by an unprecedented combination of change in climate, associated disturbances (e.g., wildfire, insects), and other changes happening globally, such as land-use change, over exploitation of resources, invasive species, pollution (high confidence). Key ecosystem properties, (e.g. biodiversity), or regulating services, (e.g. carbon sequestration), are very likely to become impaired. When ecosystem resilience is exceeded, the response will very likely be characterized by threshold-type responses, some irreversible on time-scales relevant to human society (e.g., such as disruption of species' ecological interactions and major changes in ecosystem structure and disturbance regimes—especially wildfire and insects), and the loss of biodiversity through extinction being irreversible on any time scale.

With rapid warming, ecosystems and species are very likely to show a wide range of vulnerabilities that depend on imminence of exposure to ecosystem-specific, critical thresholds (very high confidence). The most vulnerable ecosystems include coral reefs, the sea ice biome and other high latitude ecosystems (e.g. boreal forests), mountain ecosystems and Mediterranean-climate ecosystems (high confidence). The least vulnerable ecosystems include savannas and species-poor deserts, but this assessment is especially subject to uncertainty relating to the CO_2 fertilization effect and disturbance regimes such as fire (low confidence).

Since the Third Assessment Report we have many more studies analyzing the changes in the flora and fauna over longer time series. A notable number of wild animals and plants on all continents are already exhibiting discernible changes in

response to regional climatic changes. This is as we expected, because temperature is central to the lives of all living organisms. Many plants and animals have and will probably continue to adjust in several ways, including: 1) shifts in the densities of populations of species either by extending their range boundaries both toward the poles (e.g., North in the US) and up in elevation, or populations numbers shifting from one portion of their range to another (e.g., the center of the abundance pattern moving up in elevation), 2), shifting in the timing (i.e., phenology) of various events occurring in spring, which is quit common, or autumn, which is less common, 3) changes in the genetic, behavioral, morphometrics (e.g., body size or egg size), or other biological parameters, and 4) local extinction or global extinction, the latter of which is irreversible at any time scale.

Changes In Ranges And Shifting Densities

As the globe warms we find that species in North America are extending their ranges north and up in elevation, because habitats in these areas have now warmed sufficiently to allow colonization. The movements (dispersal) of species forced by rapidly rising temperatures, however, are frequently slowed and often blocked by numerous other human-made stresses, such as land-use changes, invasive species and pollution. Consequently, individuals that are moving north or up in elevation have to navigate around, over or across freeways, agricultural areas, industrial parks, and cities.

Species near the poleward side of continents (e. g., South Africa's fynbos) will have no habitats into which they can disperse as their habitat warms. The same is true for species living near the tops of mountains. Additionally, species living in these areas will be further stressed by species from farther inland or farther down the mountain moving into their habitats. Because of the heat stress and the new species with which they must interact, many species currently on islands, on the poleward side of continents and near the tops of mountains could go extinct unless humans move them to another location and make sure they survive there.

The need for species to track certain temperatures could cause wildlife managers to face a number of novel challenges over the next several decades. To date, preservation practices are generally ill prepared to deal with the challenges of rapid climate change and effective adaptation responses are likely to be costly to implement. For example, at least some managed species or species of concern will need to move as the globe warms. This could easily mean that many species currently protected in wildlife refuges or national parks could easily need to disperse to new habitats on less protected lands. These new habitats occupied by these previously managed species and species of concern may not be conducive to protecting species. This is certainly a very likely problem that needs some advance thought and planning.

Throughout pre-historic and more recent times, species have been found to move independently from other species in their community or ecosystem; species move at different rates and directions, depending on their unique metabolic, physiological and other requirements. This independent movement, will probably become increasingly evident the higher the temperature becomes. Such differential movement could result in a disruption of the connectedness among many species in current communities. This could cause a tearing apart of communities, which could disrupt biotic interactions such as predator-prey relationships. For example, if the range of a predator shifts and the range of its prey does not, a population balance becomes disrupted—a perceived benefit if the prey is an endangered species. If, however, the prey is a food-crop pest, then humans could certainly see the increase in its population as detrimental.

Disruption of biotic interactions could jeopardize the sustainability of ecosystem services on which we rely and could also lead to numerous extinctions. Substantial changes in the structure and functioning of terrestrial and marine ecosystems are very likely to occur with warming of 2 to 3°C above pre-industrial levels and associated increased atmospheric CO_2 (high confidence). Major biome changes, such as emergence of novel biomes, and changes in species' ecological interactions, with predominantly negative consequences for goods and services, are very likely by, and virtually certain beyond those temperature increases.

Progressive acidification of oceans due to increasing atmospheric carbon dioxide is expected to have negative impacts on marine shell-forming organisms (e.g., corals) and their dependent species. Indeed, by 2100 ocean pH is very likely to be lower than during the last 20 million years.

Changes in Timing

Another change that has been already seen occurring in species on every continent is shifting in the timing (i.e., phenology) of various events primarily occurring in spring but also to some extent in the autumn, such as frogs breeding earlier,

cherry blossoms blooming earlier and leaves turning color later. Over the last 30 years, around 115 species (plants and animals together) from locations around the globe were found to be changing the timing of a spring event earlier by around 5 days per decade. Only 6 out of the 115 species (5%) showed a later change in timing of their spring events (Fig 1).

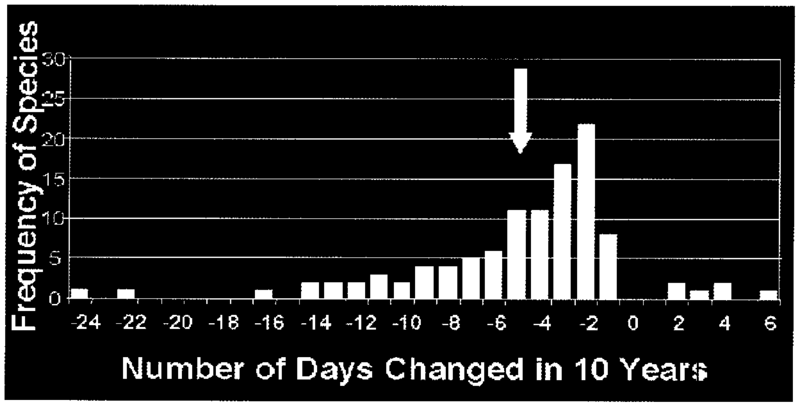


Figure 1 The number of species (both plants and animals) from around the globe with a spring trait changing by number of days per decade. Positive numbers mean the trait is happening later over the years, while negative numbers are for traits happening earlier. The "X" indicates species showing no change were not considered. The average number of days changed per decade is 5.1 (the arrow).

Rapid phenological changes of species could be problematic. For example, farmers may need to respond to warming by changing the timing of their planting and even the type of crop grown. Either of these changes could allow an insect, which was previously limited by the availability of food, the ability to grow in population size. If the insect feeds on the nectar from the flowers of the crop, then the farmer could benefit from the crops being pollinated. If, however, the insect feeds on the tissue of the crop plant, then the larger insect population could be a detriment.

Changes in Genetics, Behavior, and Other Traits

Studies investigating how rapidly warming temperatures are affecting genetics, behavior and other species' traits are relatively uncommon thus far, but the findings are significant. For example, a behavioral change associated with global warming is the foraging habits of polar bears. As the globe has warmed, these bears are increasingly foraging by necessity in garbage dumps. Bears normally hunt seals, but capturing seals requires bears to be standing on sea ice. With global warming the ice is thinning and melting earlier in the spring and freezing later in the fall. Both the type of food and quantity are no longer sufficient to sustain the previous number of bears. Hence, the population size of these bears has dropped. Additionally, other animals that depend on the polar bear as a keystone species (e.g., arctic fox and ivory gull) may also be in significant trouble as the bears catch fewer seals, leaving fewer carcasses on the ice for these other scavengers.

Another example is a North American mosquito. When the days become a certain length, it goes into dormancy. But what determines the length of the day that triggers the dormancy is genetically controlled. With global warming the habitats where this mosquito is found are staying warmer longer in the fall, which means shorter day are warmer. Now the genetic control of the day-length trigger has changed to a shorter day length.

Extirpation and Extinction

The escalating rise in average global temperatures over the past century has put numerous species in danger of extinction. "Functionally extinct" species, or species we can anticipate to be very highly likely to go extinct, include those that cannot move to a different location as the temperature increases due to either lack of available habitat or the inability to access it. Without human assistance the probability of extinction is quite high. For example, pikas are currently living in the Rocky

Mountains where the ambient temperature is quite close to the maximum this small mammal can endure. Moving up in elevation to cooler regions is not possible because the stony habitat needed by pikas is generally not available higher up on mountains. Another example is a subspecies of a checkerspot butterfly in Baja California. It will probably go extinct in the near future because it too has a low tolerance to hot temperatures, but cannot shift in to cooler regions because Tijuana and San Diego are blocking its way.

Money, land, personnel, or political will are not available for such endeavors to occur, and also absent is the long-term commitment to translocate even half of the functionally extinct species we know of today. Consequently, many scientists predict that we are standing at the brink of a mass extinction that would be caused by one very careless species.

Roughly 20-30% (varying among regional biotas from 1% to 80%) of species assessed so far (in an unbiased sample) are likely to be at increasingly high risk of extinction if global mean temperatures exceed 2-3°C above pre-industrial temperatures (1.3-2.3o C above current) (medium confidence). For example, with warming of 2.8°C above pre-industrial, sea ice declines according to some projections causing polar bears to face a high risk of extinction in the wild, which could increase the risk extinction of species relying on polar bears (e.g., Ross gull eating seal-kill leftovers). Other ice-dependent species, not only in the Arctic but also in the Antarctic, are facing similar situations. Given that there are around 1.7 million identified species on the globe, somewhere between 340,000 and 570,000 species could go extinct primarily due to our negligence. Extinctions are virtually certain to reduce societal options for adaptation responses.

Future Projection for Wild Plants and Animals

A primary adaptation strategy to climate change and even current climate variability available to managers is to reduce and manage other stresses on species and ecosystems, such as habitat fragmentation and destruction, overexploitation, eutrophication, desertification and acidification. Significant disturbances to wild habitats, including extractive use and fragmentation, are very likely to impair species' adaptation.

Given our observations of what has happened to species under different external pressures, whether they are natural or human caused, we are able to predict what might happen to species under a variety of changes. Indeed, predicting the ecological consequences of species based on pressures that actually happened may validate these forecasts. Reliable forecasting of responses of species can be invaluable to managers and policy makers, because it could help prevent negative surprises in one of two main ways. The first is by indicating which change is most likely to occur, thereby indicating what management practice(s) are needed to help avert negative surprises. The second is for those changes that cannot be managed effectively be well understood, making us better prepared for the incipient changes.

The Cause of the Rapid Warming

Species can be used to help understand what may be causing the climate to change so dramatically. Many studies have been done showing that several species are shifting the timing of various spring events. These trends have been associated with the trend in observed temperatures around the location where the species were studied. These two trends can be correlated with each other to quantify the strength of the relationship.

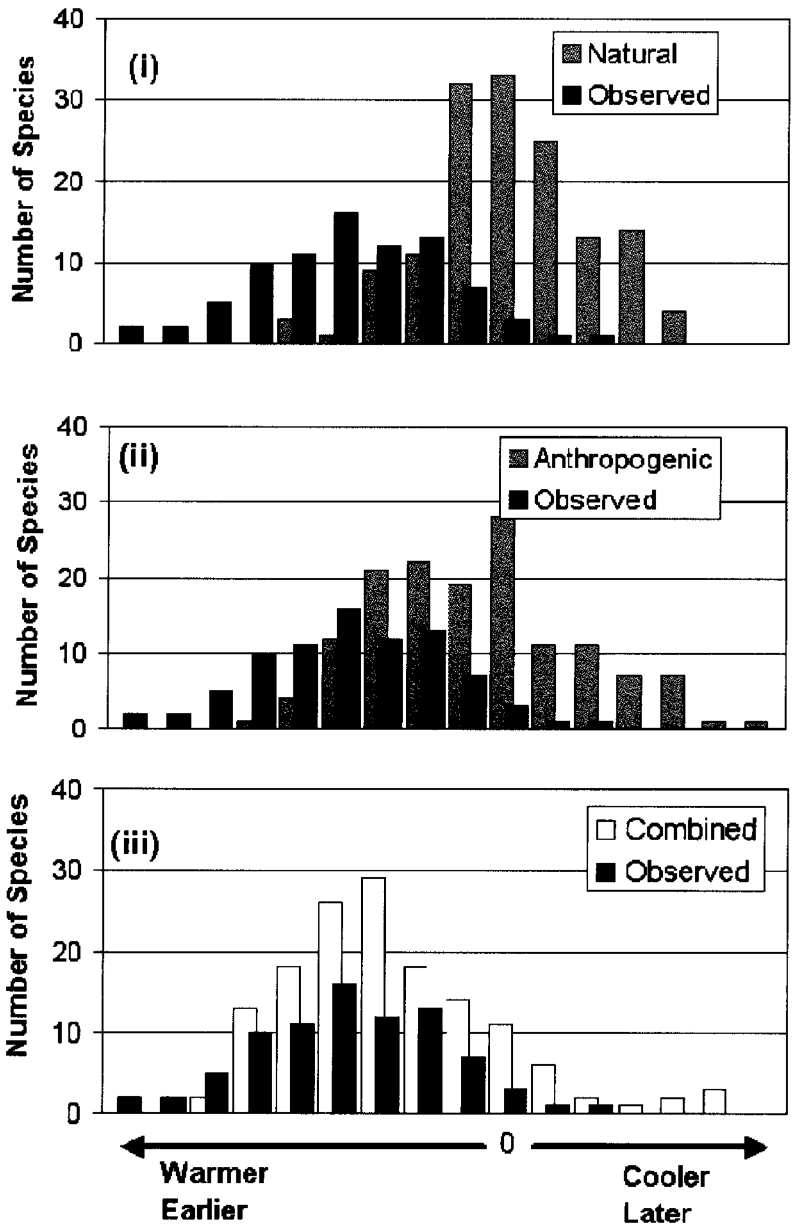
To determine if humans are having a measurable influence in the increasing temperatures, models need to be used. For the same locations and the same time periods that the species data were collected, temperatures were modeled (using HADGM3) in three different ways. First, only natural factors that cause the climate to change (e.g., sunspots, volcanic eruptions) are included in the model. Second only human factors that influence the climate are included (e.g., greenhouse gases, particulates). Finally, the model is run with both of these types of factors combined. These three different types of modeled temperatures are determined for all the species recorded at various locations around the northern hemisphere (southern hemisphere studies of species trends are rare) for the same years of each of the particular studies.

The trends for each species at each location are compared separately to the trends of the observed temperatures, the trends of modeled temperatures with only natural forcings, the trends of modeled temperatures with only human forcings, and the trends of modeled temperatures with the combined forcings. With each comparison a correlation coefficient may be calculated. There are 145 correlation coefficients derived for the species data compared to each of the three modeled temperatures. Only 86 correlation coefficients were calculated for the observed temperatures and species

trends (observed temperature data were only available for 86 species). The number of similar correlation coefficients is counted and the counts plotted.

Figure 2 shows the plots of these sums. The purpose is to compare the associations of the different modeled data with that of the observed data. Consequently, the plot or histogram of the observed data is plotted in all three panels. The top panel shows the comparison between the observed histogram and the natural-forced histogram. The agreement is not very good. The next panel shows the comparison between the observed histogram and the human-forced histogram. The agreement is better. The bottom panel shows the comparison between the observed histogram and the combined histogram. The agreement is quite good and statistical analyses show that the last agreement is statistically significant. Certainly a study such as this one needs to be done using more than one model, but certainly these results suggest that species are changing in response to regional temperature changes, and the regional temperature changes are being measurably influenced by human forcings (e.g., greenhouse gases). This indicates that humans, directly through emission of greenhouse gases into the atmosphere, are causing significant ecological consequences that could be detrimental in the future, not only to other species but also to us.

Figure 2. Plotted are the frequencies of the correlation coefficients between the timing of changes in traits (e.g., earlier egg-laying) of 145 species and modeled (HADCM3) spring temperatures for the grid-boxes in which each species was examined. At each location, all of which are in the Northern Hemisphere, the changing species' trait is compared with modeled temperatures driven by: (a) Natural forcings (maroon bars), (b) anthropogenic (i.e., human) forcings (orange bars), and (c) combined natural and anthropogenic forcings (yellow bars). In addition, on each panel the frequencies of the correlation coefficients between the actual temperatures recorded during each study and changes in the traits of 83 species, the only ones of the 145 with reported local-temperature trends, are shown (blue bars). On average the number of years species were examined is about 28 with average starting and endings years of 1960 to 1998. Note that the correspondence: a) between the natural and actual plots is weaker ($K=60.16$; $p>0.05$) than b) between the anthropogenic and actual ($K=35.15$; $p>0.05$), which in turn is weaker than c) the agreement between combined and actual ($K=3.65$; $p<0.01$). Taken together, these plots show that a measurable portion of the warming regional temperatures to which species are reacting can be attributed to humans, therefore showing joint attribution (After Root et al. 2005).



Ms. BORDALLO. Thank you very much, Dr. Root.

I now recognize Ms. Medina to testify for five minutes.

STATEMENT OF MONICA MEDINA, ACTING DIRECTOR OF THE INTERNATIONAL FUND FOR ANIMAL WELFARE, UNITED STATES OFFICE

Ms. MEDINA. Good morning, Madam Chairwoman and Members of the Subcommittee. I am Monica Medina of the International Fund for Animal Welfare or IFAW. IFAW is a nonprofit organization with offices in 16 countries around the world. We work to improve the welfare of wild and domestic animals throughout the world.

Thank you for the opportunity testify before you this morning with this distinguished panel on this most important subject, the impact the changing climate is having on marine mammals in Alaska.

In fact, this hearing is quite timely. This morning a group of over 20 environmental and animal welfare groups is announcing the formation of a coalition to end commercial whaling and announcing new poll results that show overwhelming public support for whale conservation.

The testimony I give today is derived from a report that IFAW will soon publish entitled On Thin Ice: The Precarious State of Arctic Marine Mammals in the U.S. Due to Global Warming. The report is based on a 2006 white paper written by Stacey Marz of The Ocean Foundation in which she undertook a comprehensive survey of all the recent scientific literature on the subject. Stacey and I then collaborated to create the report from her original white paper. The report has been jointly funded by The Ocean Foundation, the Wallace Global Fund and IFAW.

The Alaskan North Pacific and Arctic Oceans, their seas, bays, fjords and ice pack, are home to a dazzling array of marine mammals. This region contains some of the most pristine habitat and largest assemblages of ice dependent marine mammals in the world.

These animals—ice seals, polar bears, walruses and bowhead whales—are uniquely adapted to exist in one of the most extreme environments on the earth, the frozen Arctic, yet despite the fact that their habitat is remote and relatively pristine, these marine mammals are facing very serious threats from global warming, the sources of which originate far from the Arctic.

For animals adapted to a frozen world, the loss of sea ice will be catastrophic. Every ice dependent marine mammal species in the United States is either already showing adverse impacts from climate change or is projected to be affected in the near future.

Here are just a few examples: Polar bears are drowning when the melting ice recedes, leaving vast stretches of open water for them to navigate. Reduced food availability has resulted in decreased body condition and starvation of polar bears and even cannibalism off the north coast of Alaska and Canada.

Ring seals cannot make layers between sparse snow to protect their newborn pups from cold and predators. Ribbon seals, which lack the wariness of seals that live farther into the polar bear territory, are likely to be heavily preyed upon if they move north with the receding ice.

Ice seals and walruses, which haul out on ice flows to rest, give birth and raise their pups, are forced farther north and into deeper

waters because the area that freezes each year is shrinking. Mother walruses are abandoning their dependent young in deep, ice free waters where foraging is impossible and haul outs are nonexistent.

The bowhead whale's prey-rich waters may change in productivity as open water increases and other species move into their habitat competing for food and space.

Ice habitat is so integral to the existence of Arctic marine mammals that the rapid loss of sea ice and the cumulative effects of other climate impacts appear to set the stage for drastic reductions in populations and ultimately the extinction of these species. Current mitigation measures are few and at best can only address the symptoms of climate change.

Worse than what we know is that there is much, much more that we do not yet understand about the profound changes occurring in the Arctic. Evidence linking decline in Arctic marine mammals to climate change is limited by inadequate historical population estimates. For example, we simply do not know what bear populations might have been 50 years ago.

Moreover, increased understanding of the ecology of individual species is needed as a basis for determining what else should be examined or done to conserve these species, as my co-panelist so eloquently just explained.

In short, there is much more study of the Arctic region and marine mammals that live there urgently needed to better comprehend the effects of the decreased extent of the ice, as well as the more subtle changes in the distribution of ice and snow that affect the ecology of individual species.

Global warming also creates winners and losers among humans in areas that have historically been off limits to most human uses. The loss of ice opens up areas of the Bering, Chukchi and Beaufort Seas and the Arctic Ocean for transportation and for the new development of oil and gas deposits, fishing grounds and shipping routes, which will degrade this pristine environment and further jeopardize the animals that live there.

In my view, the Federal government must aggressively employ all of its authorities under law and via international agreements and engage the relevant management authorities to create systemic protections for ice dependent marine mammals. Specifically, the government must use the Marine Mammal Protection Act and the Endangered Species Act to begin to take actions that will conserve these animals and their habitat.

Immediate actions are needed, and I urge Congress to act now to increase funding for research and stock assessments of ice dependent marine mammals and to close the loophole in the Marine Mammal Protection Act that permits the importation of polar bears—trophies—hunted in Canada. Taking these steps will set the stage for providing relief to ice dependent marine mammals in the U.S.

It is also clear that Congress must take a leadership role in establishing mechanisms to reduce greenhouse gas emissions. Absent such action, we can expect mass extinction of these amazing animals within this century. Such a tragic loss of species and biodiversity will have far reaching and irrevocable effects throughout the

entire vast Arctic ecosystem, including the subsistence and cultural uses of these animals by Alaska Native peoples.

I want to close by thanking my son, my 10-year-old son, Daniel, for inspiring me to do this work to save the polar bears. It is a grave concern to him.

Thank you very much for the opportunity to testify. I would be pleased to answer any questions you may have at the end of the panel's opening statements.

[The prepared statement of Ms. Medina follows:]

Statement of Monica Medina, U.S. Deputy Director, The International Fund for Animal Welfare (IFAW)

Good morning. I am Monica Medina, the Acting Director of the U.S. office of the International Fund for Animal Welfare (IFAW). IFAW is a non-profit organization with offices in fifteen countries around the world. We work to improve the welfare of wild and domestic animals throughout the world by reducing the commercial exploitation of animals, protecting wildlife habitats, and assisting animals in distress. Thank you for the opportunity to testify before you today on the devastating impacts that the changing climate is having on marine mammals in Alaska.

The testimony I give today is based on a report that IFAW will publish soon entitled "On Thin Ice: The Precarious State of Arctic Marine Mammals in the U.S. Due to Global Warming." The report is based on a 2006 white paper written by Stacey Marz of The Ocean Foundation. Her research was originally funded by the Alaska Oceans Program of the Alaska Conservation Foundation and the George H. and Jane A. Mifflin Memorial Fund. IFAW agreed to assist in the editing of the white paper into a condensed report for public release. Stacey and I collaborated to create the report from the original white paper. Its publication is jointly funded by The Ocean Foundation, the Wallace Global Fund and IFAW. I want to acknowledge all their contributions to assembling the information I will provide the subcommittee.

The purpose of the report is to survey what is currently known about the impacts of global warming on ice-dependent marine mammal species in the U.S., including four species of ice seals (Erignathus barbatus - bearded, Phoca fasciata - ribbon, Pusa hispida - ringed and Phoca largha - spotted seals), two stocks of polar bears (Ursus maritimus - the Southern Beaufort Sea stock, Chukchi/Bering Seas stock), Pacific walruses (Odobenus rosmarus), and western Arctic bowhead whales (Balaena mysticetus)also known as the Bering/Chukchi/Beaufort Seas stock). The report also provides an overview of each of these marine mammal species, its habitat, and the relevant federal statutes, agreements and management entities that govern it. Finally, the report explains the serious threat global warming poses to these animals, and the sobering impacts that they are already experiencing as observed by biologists and Alaska Native subsistence hunters.

Most importantly, the report addresses these issues and provides tangible recommendations that policy makers can immediately do to help improve the prospects for long term survival of these animals in the Arctic. The government must aggressively employ all of its legal authorities, international agreements and management bodies to create systemic protections for ice dependent marine mammals. Specifically, the government must avail itself of all the tools it has at its disposal under the Marine Mammal Protection Act and the Endangered Species Act, and through these various management bodies, to begin to take actions that will conserve these animals and their habitat.

Immediate actions are needed—we cannot wait until a comprehensive legal and regulatory structure to reduce greenhouse gas emissions is enacted by Congress. Congress can act in the short run to increase funding for research and stock assessments of ice dependent marine mammals, and to close the loophole in the Marine Mammal Protection Act that permits the importation of polar bear trophies hunted in Canada. Taking these steps will set the stage for providing relief to ice dependent marine mammals in the United States. However, it is also clear that in the long run, unless greenhouse gas emissions are radically reduced, we can expect mass extinction of these amazing animals within this century. Such a tragic loss of species and biodiversity will have far reaching effects on the entire vast Arctic ecosystem, and the subsistence and cultural uses of these animals by Alaska Native peoples.

Background

In Alaska, ice seals, walruses, polar bears and bowhead whales rely on sea-ice as habitat in the Bering, Chukchi and Beaufort Seas. Much of these seas are covered

by sea-ice for three quarters of the year from roughly October until June. Sea-ice has a large seasonal cycle, reaching a maximum extent in March and a minimum in September. There are three major forms of sea-ice in the Arctic: (1) shorefast or landfast ice that is attached to the shore and relatively immobile, extending to variable distances offshore; (2) stamukhi ice that consists of thick ridges that become grounded during the winter and attach to the ocean bottom; and (3) pack ice that includes first-year and multiyear ice and moves under the influence of winds and currents. Leads and open water areas form within the pack ice zone.

Each ice-dependant marine mammal species is precisely adapted to this harsh environment. Each species prefers different types of ice and uses it in different ways that are suited to its biological characteristics. These animals rely on this ice environment as a platform for resting and foraging, breeding, traveling, protection, pupping, nursing and mating. They largely follow the movement of the ice in their migration patterns.

There are several serious issues of general concern that affect all ice-dependent marine mammals. The issues range from simply not having adequate background information about the different species' populations to the sobering projection that their ice habitat is disappearing due to climate change and will be gone within this century. Related to climate change and the loss of sea-ice, there are additional concerns about what emerging human uses will be made possible by more open water in the northern seas and Arctic Ocean. These uses include increased oil and gas activities, the development of new commercial fisheries, new and emerging shipping routes, and increased disturbance and pollution in the ecosystem due to the newly possible human activities. There is also concern about bioaccumulation of contaminants in Arctic marine mammals.

There is a surprising shortage of background information about almost all ice-dependent marine mammals. This can be attributed to the difficulty of studying animals in a very remote and extreme environment, and the expense of both physically accessing the animals and using the appropriate technology to survey them. With the exception of bowhead whales and the Southern Beaufort Sea polar bears, there are no reliable abundance estimates for any of the four ice seal species, the Pacific walrus or the Chukchi/Bering Seas polar bear stock. Also, there is no information about population trends for these animals and no potential biological removal rate. As such, it is virtually impossible to discern the overall health of these marine mammal species, and how much loss of individual animals the stocks can sustain.

Considering the threats ice dependent species currently face and are likely to face in the future, it is troubling to have so little background information. It is critical that research is undertaken as soon as possible to collect reliable background abundance information, to monitor population trends, to identify sustainable take levels and to evaluate if and how human-caused and natural events are affecting the populations. In addition, as human activities increase in the Arctic it will become more important to monitor those activities for possible impacts on ice dependent marine mammals, their prey and their habitat, in order to detect harmful changes as early as possible. Moreover, research is needed to understand the cumulative effects of all issues of concern—climate change, oil and gas activities, and contaminants—on these animals to inform management actions and to mitigate against adverse impacts within our control. The current level of financial support for research limits informed decision-making about the status of Arctic marine mammals, now and in the future. Adequate funding is critical to support efforts by management agencies, their research collaborators and academic institutions to comprehensively survey and study the ice dependent marine mammals.

With that background, I will now discuss what is known about the impacts of global warming on each of the four marine mammal species in Alaska. In addition, I will make recommendations about actions the government can take in the near term to begin to mitigate and address the issues they face due to the loss of polar ice habitat.

Ice Seals

Ice seals spend the majority of time on the ice, and use ice as a platform from which to feed, to birth their pups and to rest. They migrate northward with the ice during the warmer months. Their reliance on sea-ice means that they will be severely impacted as the sea-ice diminishes due to climate change. Each of the four seal species found in arctic Alaska will be affected by the loss of sea-ice in different ways based on their specific habitat preferences and their unique biological characteristics.

For example, ribbon and spotted seals that currently live at the southern edge of the polar bears' range could expand their range northward. This could greatly affect ribbon seal populations if their habitat shifts north into polar bear territory as the

ice shrinks, because polar bears may prey heavily upon ribbon seals which do not have the wariness of seals that currently live near polar bears. Moreover, the absence of ice in southern pupping areas or the relocation of pupping to more northern areas could affect seal reproduction. In addition, crowding in birthing areas because of a reduction in the quality of the ice may also increase the risks of disease transmission.

Ringed seals prefer stable, shore-fast ice for construction of birth lairs. Adequate snow drift accumulation is necessary to protect pups in lairs with thick roofs. Access to birth lairs for thermoregulation is considered critical to the survival of nursing pups when air temperatures fall below freezing. For the past six years, ringed seals have abandoned lairs increasingly early as spring temperature and snow melts have advanced. The transition from lair use to basking on the surface was especially early and abrupt in 2002, and by mid-May all the seals had abandoned their lairs. Many pups in their natal coats were resting on the ice in the open instead of in lairs as is usual in mid-May. The early snow melts that researchers have observed are consistent with a general pattern observed in the Beaufort Sea. Premature lair abandonment by ringed seals, associated with early snow melts, likely will increase juvenile mortality rates due to exposure to freeze-thaw conditions and predation. When lack of snow cover forced birthing to occur in the open, nearly 100% of the pups died from predation.

In addition, increased rain on snow during the late winter damages or eliminates snow lairs, which increases pup exposure to hypothermia and predation. Researchers believe that if early season rain becomes regular and widespread in the future, ringed seal pup mortality will increase especially in the more southerly parts of their range. Consequently those local populations may be significantly reduced.

Researchers have reported that an early spring breakup negatively impacted the growth, condition and probably the survival of un-weaned ringed seal pups. Early breakup likely interrupted lactation in mother seals which negatively affected the condition and growth of pups. Earlier ice breakups are predicted to happen more frequently and result in decreased ringed seal productivity and abundance. Moreover, in addition to loss of habitat, the seals may also have to contend with the related loss of their major food sources. Arctic cod is one of the ringed seals' primary prey species. It is strongly associated with sea-ice throughout its range and uses the underside of the ice to escape from predators. It is likely that a decrease in seasonal ice cover could have adverse effects on Arctic cod and consequently affect its availability to ringed seals as food.

Recommendations for Ice Seal Conservation

Federal funding for the study of ice seals must be increased so that further research can be undertaken. It has been decades since there has been any comprehensive study on population numbers and distribution of ice seals. Without this critical information, it is impossible to know how rapidly the seal populations are declining, much less to make intelligent management decisions regarding subsistence hunts. At the very least, the government should conduct assessments of these stocks to determine whether they are depleted and develop conservation plans as required under the Marine Mammal Protection Act. Further, in order to ensure that these seal species do not reach the brink of extinction without us even knowing it, we recommend that the government consider whether to propose listing these seal species under the Endangered Species Act. The challenges faced by these seal species are not appreciably different than those faced by polar bears, which the government recently proposed for listing.

Polar Bears

Polar bears are the largest of all land predators, with males weighing up to 1,700 pounds and standing 2-3.5 meters tall. They are a potentially threatened species living in the circumpolar north in Alaska, Canada, Russia, Greenland and Norway. In Alaska there are two populations: (1)the Southern Beaufort Sea population, which occurs along the North Slope of Alaska and ranges into western Canada; and (2) the Chukchi/Bering seas population, which occurs off western Alaska with its range extending to Wrangel Island and eastern Siberia. This is a shared stock with Russia. Only the Southern Beaufort Sea population can be reliably estimated with certainty. The Polar Bear Specialist Group of IUCN, the pre-eminent international scientific body for research and management relating to polar bears, estimated the population at 1,800 bears. The Chukchi Bering Sea population is estimated at 2,000, but that number is unreliable due to widespread poaching in Russia.

Polar bears are superbly adapted for Arctic survival, with physical characteristics that make them especially suited to live in the extremely cold ice environment. The polar bears' water-repellant white coat helps it blend into the snow and ice and they

have dense under fur. Their bodies are entirely fur covered except for their nose, and they have a thick layer of insulating fat (up to 4.5 inches thick) that keeps their body temperature and metabolic rate stable at -34 degrees F. Their claws are suited to walking on ice and grasping prey along with "suction cups" on the underside of their feet for increased ice traction. Also, their enormous, oar-like feet make them expert swimmers and spread their weight on the ice. Polar bear are specialized for a carnivorous diet because they have an acute sense of smell for finding seals in snow caves.

Polar bears have received much media attention in recent years due to their high profile connection to their shrinking sea-ice habitat. In June 2005, 40 members of the IUCN Polar Bear Specialist Group/Species Survival Commission of the World Conservation Union concluded that polar bears should be classified as a "vulnerable" species based on a likely 30% decline in their worldwide population over the next 35 to 50 years caused principally by climatic warming and its consequent negative affects.

In Alaska, there is evidence of decreased body condition, death from drowning, cannibalism and starvation. In three of the past four years, there have been record low ice packs in Alaska's Beaufort Sea region, pushing more and more polar bears onto land for protracted periods, with bears congregating around whale carcass sites, village dumps and other settled areas where they may increasingly come into conflict with people. Observed and predicted changes in sea-ice cover and the timing of freeze-up and break-up have profound effects on polar bears. The Polar Bear Specialist Group of IUCN reports the following expected effects from climate change:

- Changes that alter the period of ice coverage could affect polar bear distribution and impact their condition:
  - With ice pack shrinkage, bears may spend greater amounts of time on land
  - Bears will likely more extensively use terrestrial areas, ultimately affecting their physical condition from relying on fat stores for energy
  - Bears with decreased physical condition could effect production and survival
  - Bears using deteriorating pack ice may experience increased exertion associated with movements and swimming
- Climate changes on prey species will have a negative effect on polar bears:
  - decreased snow or increased seasonal rain patterns could effect ringed seal pupping by not having adequate snow for construction of birth lairs or increased rain fall can collapse birth lairs and reduce seal productivity
  - increased snow can result in reduced success in entering ringed seal birth lairs
  - prey reductions could effect polar bear condition and ultimately cub production and survival
- Denning could be impacted by unusual warm spells:
  - access to high quality denning areas may be limited or restricted
  - use of less desirable denning habitat could have impacts on reproduction and survival
  - rain or warming could directly cause snow dens to collapse or be opened to ambient conditions
  - loss of thermal insulative properties in opened dens could effect cub survival

The best information on the effect of global warming on polar bears comes from the western coast of Hudson Bay in the Canadian province of Manitoba. Sea-ice has been breaking up there three weeks earlier than it did decades ago. Bears must spend an extra month on shore fasting, waiting for ice to re-form in the fall. As a result, the western Hudson Bay population has plunged 22% from 1,194 in 1987 to 934 in 2004. Canadian scientists have observed that today's polar bears are smaller in stature, weigh less, and have fewer cubs. Scientists estimate that for every week of delay in freeze-up, polar bears lose at least 22 pounds of critical fat reserves. Pregnant females are losing so much weight that they fail to produce enough milk for their cubs, which then suffer increased mortality. Once females fail to attain a minimum weight they will not give birth at all, and scientists can already document a 15% drop in birth rates. As polar bears are spending more time on land, there has been an increase in people killing curious and aggressive bears in self defense.

In addition, polar bears are expending more energy because of reduced ice thickness and extent. Arctic sea-ice circulation is clockwise and polar bears tend to walk against this movement to maintain a position near preferred habitat within large geographical home ranges. Ice thickness is diminishing and there is increased transport of multi-year ice from the polar region. This increased rate and extent of ice movements requires polar bears to work harder to maintain their position near preferred habitat. As sea-ice moves more quickly or becomes more fragmented, polar bears will likely use more energy to maintain contact with consolidated ice. During summer periods the remaining ice in much of the central Arctic is now positioned

away from more productive continental shelf waters and over much deeper, less productive waters in the Beaufort and Chukchi Seas. As the open water enlarges, bears will spend more time and energy swimming in transit. In 2004, scientists documented for the first time four polar bear drownings in open water off Alaska and extrapolate that 27 bears may have drowned during that event after trying to swim between shore and distant ice.

Researchers suggest that as habitat patch sizes decrease, available food resources will also decline, resulting in reduced polar bear residency time and increased movement in search of food. As discussed earlier, the polar bear's primary prey—ringed seals are projected to decline from reduced sea ice habitat, and decreased snowfall that prevents adequate birth lairs to protect ringed seal pups from freezing air. Polar bears cannot offset energy losses from decreased seal consumption by using terrestrial habitat because food such as berries, snow geese and caribou do not represent significant energy sources and nutritional stress will result. The consequences of increased energetic costs to polar bears are reduced weight and condition and corresponding reduction in survival and recruitment rates.

Declines in fat reserves during critical times in the polar bear life cycle are likely to lead to an array of impacts. These include: delay in the age of first reproduction, fewer females with adequate fat reserves to complete successful denning, decline in litter sizes with more single cub litters and fewer cubs overall, lower cub body weights and lower survival rates. When mother bears and their cubs leave the den, their body masses are correlated; heavier females produce heavier cubs and lighter females produce lighter cubs. Researchers are seeing decreased body condition of southern Beaufort Sea polar bears. Cub survival rates declined significantly when comparing rates from 1967 to 1989 and 1990 to 2006. The lower cub survival rate coincided with warming temperatures and altered atmospheric circulation starting in the winter of 1989-1990 that caused an abrupt change in sea-ice conditions in the Arctic basin. In addition, broken and fragmented ice conditions may cause cubs to be in the water longer, increasing the chance of hypothermia or death because they cannot survive more than 10 minutes in icy water. In the Western Hudson Bay, declines in cub survival and physical size were seen for several years before a statistically significant decline in the population size was confirmed. Polar bear experts believe that if the trends in sea-ice loss continue, the southern Beaufort Sea population will significantly decline within the next 45 years.

Polar bears in the Southern Beaufort Sea may be turning to cannibalism because longer seasons without ice keep them from getting to their prey—ringed seals. From January to April 2004, in the region north of Alaska and western Canada, researchers found three instances of polar bears preying on each other, including the first-ever reported killing of a female in a den shortly after it gave birth. Adult males are believed to have actively stalked or hunted the bears before attacking and eating them.

Recommendations for Polar Bear Conservation

The effort underway by the government to list the polar bear as a threatened species under the Endangered Species Act is an important first step in polar bear conservation. This process, which can be quite lengthy, should be undertaken as quickly as possible. The government should not allow the process to be bogged down by opponents of the listing. In the meantime, the government should take other steps to conserve polar bears out of an abundance of caution. For example, the Congress should close the loophole in the Marine Mammal Protection Act that permits Americans to hunt polar bears in Canada and return home with their bear trophies. Each year approximately 200 bears are killed by American hunters. It is illegal to hunt these bears in the U.S. The Marine Mammal Protection Act should be amended to prohibit these trophies from entering our borders.

Pacific Walrus

Walruses are the largest pinnipeds in the Arctic and sub-Arctic seas, with a geographic range that completely encircles the polar basin. The Pacific walrus, which accounts for 80 percent of the world's walrus population, is one of two geographically isolated subspecies of walrus. The Pacific walrus is found in the North Pacific Ocean's Bering Sea and in Arctic waters from the East Siberian Sea to the western Beaufort Sea, as well as in the Laptev Sea.

They are most commonly found in relatively shallow water areas, close to ice or land. Walruses spend about half their time in the water and half their time on beaches or ice floes where they gather in large herds. They forage from ice above the continental shelf for bottom-dwelling invertebrates. The mouth of the walrus is uniquely adapted to allow them to eat buried clams and invertebrates. The walrus squirts high-power jets of water out of their mouths like a water drill to unearth

clams mired in the mud at the bottom. Scientists believe that they then use strong suction to remove the fleshy parts of the prey away from the shell and then discard the shell. This intensive tilling of the sea bottom releases nutrients into the water column, provides food for scavengers such as starfish, and increases the patchiness of the bottom, which likely plays an important community structuring function for benthic and pelagic animals.

Walruses may already be feeling the impacts of climate change in Alaska. They use ice as a platform for resting and from which to forage. They can only dive to depths of approximately 90 meters; when the ice recedes north of the continental shelf, they are unable to dive as deep as their bottom dwelling prey is found. In addition, walrus calves, which have been observed swimming in open water alone, are believed to have been abandoned by their mothers who were searching for food in ice-free waters, leaving no place for the dependent calves to rest.

Pacific walruses are showing the effects of global warming associated with the changing distribution and extent of pack ice in the Bering and Chukchi Seas. Currently, there are no data upon which to make reliable predictions of the net impacts that changing climate conditions would have on the status and trend of the Pacific walrus population. However, disturbing observations have been made in recent years about climate change impacts on walruses.

As described earlier in this section, the process walruses use to eat involves bioturbation, which is the disturbance of sediment layers by biological activity. Bioturbation releases an extraordinary amount of nutrients, including nitrogen, into the water, which is a massive effect compared to natural release in the absence of walrus feeding. Researchers believe that walruses return to the same drifting ice floes from which they left to forage in the water. The loss of sea-ice due to climate change will result in diminished extent and configuration of ice platforms from which walruses will feed and bioturbate the benthic environment.

As noted above, walruses are distributed only over continental shelves because they feed on benthic invertebrates and cannot effectively feed at depths beyond 90-100 meters. After breeding on the winter ice in the Bering Sea, the males retreat to coastal areas while the females and young (up to age three) retreat with the ice into the Chukchi Sea. There they feed intensively in between periods of resting and nursing their young on the ice.

In 1998, the sea-ice in the Chukchi and Beaufort Seas retreated unusually far to the north and by September it covered 25% less of the Arctic Ocean than during the minimum for the previous 35 years. Vessel-based researchers surveying walruses found that substantial portions of the ice edge had receded north of the continental shelf where the water was too deep for walruses to feed. Continued warming and reduction in ice over the continental shelf in summer and fall will likely reduce the amount of forage available to lactating walruses. The result may be a reduced survival of nursing calves if female walruses respond by concentrating on ice or shorelines near feeding areas. This will result in a corresponding increase in their risk of predation by polar bears. There have also been reports of mother walruses following the retreating ice and abandoning their calves in open water because the calves cannot keep up, which creates yet another possible method of mortality.

Moreover, the calves have been reportedly abandoned on the ice as well. In April 2006, the Aquatic Mammals journal stated that walrus calves had apparently been stranded far offshore by melting sea-ice in the Arctic Ocean. During a summer 2004 cruise in the Canada Basin to investigate the impact of global warming on the oceanic ecosystem over the continental shelf of Alaska, researchers aboard the U.S. Coast Guard icebreaker Healy found nine lone walrus calves swimming far from shore. The area was 53 to 134 miles from shore in water that was over 3000 meters deep. Ice was virtually absent throughout the area where the scientists saw the lone calves. Scientists had never before documented calves offshore without their mothers and had seen mothers and calves together only in water less than 100 meters deep and 20 miles from shore. The calves, which swam around the ship, barked continuously and seemed distressed and according to the researchers. These calves likely drowned or starved.

The sightings of lone calves coincided with evidence of rapidly melting seasonal ice in the shallow continental shelf region where walruses feed on clams and crabs. Researchers measured an unusually warm mass of water moving onto parts of the continental shelf north of Alaska from the Bering Sea that caused seasonal sea-ice to rapidly melt. Sea temperatures there were more than six degrees warmer than those observed at the same time and location two years earlier. In areas where sea-ice remained, the sea floor was too deep, about 2836.5 meters, for adult walrus to feed. This development is significant because walruses use sea ice as a resting platform, especially for pups when their mothers dive for food. The calves, which are dependent on mothers' milk for up to two years, cannot forage for themselves. Re-

searchers believe that the mothers had to swim farther and farther from shore to find ice for the calves to rest on and eventually had to abandon them in waters too deep for the mothers to reach food.

Recommendations for Walrus Conservation

The same course of action is recommended for walruses as for ice seals. Federal funding for the study of walruses must be increased so that further research can be undertaken. It has been decades since there has been any comprehensive study on population numbers and distribution of walruses in Alaska. Without this critical information, it is impossible to know how rapidly the walrus populations are declining, much less to make intelligent management decisions regarding subsistence hunts. At the very least, the government should conduct stock assessments of these stocks determine whether they are depleted, and develop conservation plans as required under the Marine Mammal Protection Act. Further, in order to ensure that this species of walrus does not reach the brink of extinction without us even knowing it, we recommend that the government consider whether to propose listing the Pacific walrus under the Endangered Species Act. The challenges faced by this walrus species is not appreciably different than those faced by polar bears, which the government recently proposed for listing.

Bowhead Whales

Bowhead whales are the only baleen whales that spend their entire lives in waters near sea-ice and do not migrate to temperate or tropical waters to calve. Bowheads are well adapted for living in Arctic and sub-Arctic waters. They have the thickest blubber of any marine mammal, up to .61 meters thick, which is used for insulation, food storage, and padding.

Bowhead whales are the most important subsistence animal for most northwestern and northern Alaska coastal Eskimos. The International Whaling Commission (IWC) manages the subsistence harvest, and has granted the Alaska Eskimo Whaling Commission a harvest quota. For 2002-2007, subsistence hunters received a block quota of 280 bowhead strikes allowed, of which 67 whales (plus up to 15 unharvested in the previous year) could be taken annually. This quota allows the Chukotka Natives in Russia to take 5 whales. The next five-year quota is up for renewal in May of 2007 at the annual

As a result of heavy exploitation by commercial whalers, the western Arctic bowhead whale stock is currently listed as endangered under the Endangered Species Act and depleted under the Marine Mammal Protection Act. This stock of bowhead whales is the most studied of bowhead whales in the world and because of their importance to Alaska Natives for subsistence, the International Whaling Commission's regulation of bowheads, and the sub-sea location of oil and gas reserves below bowhead habitat. Research has included obtaining reliable population estimates and trends, information about the whale's overall health, migration and stock structure.

The impacts of global warming on bowhead whales are not clearly understood yet, but it is believed that the abundance of their food may decline as more open water occurs. Also, some are concerned that gray whales may be moving into bowhead whale habitat and may compete with bowheads for space.

Climate change and the associated changes in the distribution and extent of pack ice in the Bering, Beaufort and Chukchi Seas is a large concern for bowhead whales. Bowhead whales are likely sensitive to changes in Arctic weather, sea-surface temperatures, or ice extent and the associated effect of prey availability. There is insufficient data to make reliable predictions of the net impacts that changing climate conditions would have on bowhead whales. However, the IWC has listed bowhead whales in the Eastern Arctic and Okhotsk Sea as vulnerable due to a combination of climate change and other factors.

The bowhead whale's foraging efficiency is intricately linked to the Arctic ecosystem by changes in ice cover, in spring ice break-up, in algal blooms, and in the abundance of its prey species. Bowheads, which spend their entire lives in Arctic waters, may be strongly affected by changes in the distribution or abundance of their prey in these areas. If plankton species are affected by climate change, this could lead to cascading effects through the food chain. In addition, global warming and possible shifts in wind patterns could also affect the distribution of polynyas in the polar ice cap. Dark polynyas often contain significant blooms of phytoplankton. Cetacean species such as bowhead whales that rely on ice edges for phytoplankton foraging might be adversely affected by any decline in these habitat areas.

Researchers and subsistence hunters are concerned that bowhead whales may also be impacted by gray whales migrating further northward beyond their histor-

ical range, seeking colder waters. Large pods of gray whales typically travel to the Bering Sea's northern waters each spring from Baja, California, feasting on amphipods, tiny shrimp-like creatures that live in the muck at the bottom of the shallow sea. The gray whales feed voraciously all spring and summer in preparation for a three- to five-month fast during their 12,000-mile journey back to Baja. They make the return trip in the fall, having the longest total migration of any marine mammal.

However, now the gray whales are heading north into the Chukchi Sea, above the Arctic Circle, where the colder waters support amphipods. Some gray whales are foregoing their full fall migration, going no further south than Kodiak. It is unknown exactly what effect more gray whales in the northern seas year-round will have on bowhead whales. Both bowhead and gray whale populations are increasing at approximately 3% per year. Gray whales have a broader diet than bowheads, breed faster and generally seem more capable of colonizing new areas than bowhead whales. As the gray whales shift northward, they are moving closer to the territory of the bowhead whale, which feeds offshore on krill. Some Alaskan Natives bowhead hunters are concerned that the more aggressive gray whale may interfere with the quieter bowhead, competing for space.

It has also been predicted that reductions in Arctic sea-ice will lead to an increase in ice-free days annually. Several potential concerns arise from this. The presence of sea-ice also affects the timing, nature and possible locations of human activities such as shipping, research, barging, whale hunting, oil and gas activities (seismic surveys and drilling), commercial fishing, military activities and other activities to introduce noise and pollution into the marine environment. Seasonal changes in ice extent and human activity may restrict whale movements such that patterns of gene flow are altered. Further, bowhead whale migrations and selection of wintering and summering grounds may shift in a warmer Arctic.

Recommendations for Bowhead Whale Conservation

The federal government must continue to be a forceful advocate for whale conservation at the IWC. It must make clear that the limited scope of the subsistence hunt for bowheads stands in sharp contrast to the commercial hunts conducted by other nations under the guise of scientific research. Moreover, the Alaska Eskimo Whaling Commission should continue to collaborate with scientists to ensure there is adequate data collection and documentation of changes regarding the range and population densities of bowhead and gray whales in the Arctic in order to ensure that we have as much information as possible about the impacts of global warming on the whales. The fact that there are annual subsistence hunts provides an opportunity to collect data in a consistent and timely manner about the impacts of global warming on bowhead whales, on other whales, and on the Arctic ecosystem in general.

Conclusion

The information compiled in the report makes a powerful and persuasive case that the time is now to take action. The very existence of polar bears, walruses, ice seals, and bowhead whales for future generations to enjoy is at stake. Immediate actions are urgently needed. We cannot wait until a comprehensive legal and regulatory structure to reduce greenhouse gas emissions is enacted by Congress and our greenhouse gas emissions decrease, and the warming trend eventually slows. By then it will be much too late.

Ms. BORDALLO. Thank you. Thank you, Ms. Medina.

Finally, the Chair would like to recognize Dr. Haney to testify for five minutes.

STATEMENT OF J. CHRISTOPHER HANEY, Ph.D., CHIEF SCIENTIST, DEFENDERS OF WILDLIFE

Dr. HANEY. Madam Chairwoman and Members of the Subcommittee, I am J. Christopher Haney, Chief Scientist for Defenders of Wildlife. Thank you for the invitation this morning to speak with you about the impacts of climate change on America's fish and wildlife.

My organization was founded in 1947. It is a national nonprofit organization representing more than 500,000 members and

supporters dedicated to protecting and restoring native animals and plants in their natural communities. We stand at a crucial moment when we must act, and act now, if we desire to protect the nation's natural heritage.

Conclusions reached about the changed climate that we see are compelling—they are so compelling—because the observed impacts have been consistent across species and across diverse geographic regions. The results are based literally on hundreds of plants and animals, thousands or articles dealing with climate change.

In my written testimony I describe 10 categories, major categories, of climate change impacts that currently threaten our national fish and wildlife resources. These categories include such examples as sea and land ice meltdowns; heightened risk from invasive species, including nonnative diseases like West Nile virus; ocean acidification, more intense storms and rising sea levels.

I also provide several examples of species or habitats from the districts or states that you represent that are vulnerable to climate change impacts. Though emphasizing fish and wildlife resources, both terrestrial and marine, nevertheless you can see obvious connections with human welfare as well.

Instead of repeating those technical details here this morning, let me relate to you a brief firsthand account of how climate change has altered the places and species that I study.

Exactly 20 years ago today, my Fish and Wildlife colleagues in a small, cramped office in Anchorage, Alaska, were busy preparing for a very large, major expedition that we were putting together for the remote St. Lawrence Island in the Bering Straits region of northern Alaska.

Because this island is entirely owned and administered by two native corporations, we were there as their guests. Despite the Service having stewardship or management authority over those resources, we had to go through certain protocols and procedures in order to work on their lands.

When we settled all of the organizing and eventually got out to the island, we finally arrived at a very remote campsite about 30 miles southwest of Gambell on the far southwest coast of the island toward late May. Our guide, a Yu'pik Eskimo by the name of Mr. Lane Iyacatan, showed us how and where to set up our camp.

The trick was to find sites that were flat enough to put up tents and weather ports, but also high enough to avoid the spring snow melt, the floods that were going to come later on in the season.

Now, mind you as a southerner at Memorial Day weekend the place looked more like midwinter than any place I had ever seen, and it was an eye-opening experience to see snow melt on into June and July.

A slight man of immense strength and very gracious nature, Mr. Iyacatan was very, very sparing with his words. For whatever reason, he and I seemed to hit it off, and we chose to team up to do some of the more strenuous activities in this remote camp. One of those was building bridges out of driftwood that would link the parts of our camp as the river started to rise later in the spring.

Whenever Mr. Iyacatan would finally get around to take a break, and that wasn't very often it seemed to me, he would take a slow look around at the usually gray sky, the gray Bering Sea nearby

and the mountains that ringed our camp. His typical remark was, “Kind of cold today.” That was 1987. Mr. Iyacatan would use this phrase rather less often these days.

When I return to Alaska now, I cannot help but notice the later falls, the milder weather, the disappearing glaciers. Entire villages are being moved away from crumbling shorelines that are no longer protected by the ice pack. Animals and plants certainly, but most of all the local inhabitants, know that climate change is here now. These kinds of experiences are also what convince skeptical scientists of the reality of climate change.

Let me finish by stressing that our national strategy for coping with impacts of climate change must consist of two key approaches. We must take immediate steps now to reduce the causes, mitigation. We also must treat this bottleneck that we are going to experience over the next decades or century on the effects. We also need to use adaptation.

We stand ready to work with this Subcommittee and the rest of the Congress. Thank you for this opportunity.

[The prepared statement of Dr. Haney follows:]

Statement of Dr. J. Christopher Haney, Chief Scientist, Defenders of Wildlife

Madam Chairwoman and members of the subcommittee, I am J. Christopher Haney, Chief Scientist for Defenders of Wildlife. Thank you for this opportunity to speak with you today about impacts of climate change from global warming on America’s fish and wildlife.

My organization was founded in 1947 and is a national non-profit organization with more than 500,000 members and supporters dedicated to the protection and restoration of all wild animals and plants in their natural communities. I come before you today to express our profound concern that we stand at a crucial moment in our history when we must act, and act now, if we desire to protect this natural heritage—the nation’s diverse fish and wildlife resources.

As you know, the U.N. sponsored Intergovernmental Panel on Climate Change (IPCC) recently released two out of an eventual four volume report that summarizes findings from much larger technical reports (IPCC 2007 Climate Change Fourth Assessment Report (WGI Science) Summary for Policy-Makers (SPM) and (WGII Impacts, Adaptation, and Vulnerability) SPM). The IPCC report makes clear that global warming is occurring, that it is exacerbated by human activity, and that it will have a devastating impact on fish and wildlife. The IPCC report is particularly important for two reasons.

First, the underlying technical report reflects a synthesis of the existing scientific and technical literature compiled by the world’s top experts. It represents the collective understanding of literally thousands of scientists from around the world, and includes hundreds of top university researchers and government scientists from the U.S. Therefore, these Assessment Reports summarize the current science and portray our state of knowledge about climate change and global warming. Impacts of climate change in North America were included in this report.

Second, the report is based on actual observation. In my testimony today, I wish to share with you first-hand personal observations, and will emphasize ten (10) separate categories of impacts from climate change that we at Defenders see affecting fish and wildlife resources across the country. These categories not only serve to further reinforce findings of the Intergovernmental scientific report, they will enable you to see direct connections to human welfare as well.

GLOBAL WARMING’S IMPACT ON WILDLIFE

Recent studies clearly demonstrate that species and biological communities are responding to changing climate due to global warming. The strength of these conclusions—that impacts of climate change are consistent across diverse species and

geographic regions—is based on the robust nature of the meta-analyses [1] which examined hundreds of species and thousands of articles on climate change. A 2003 study by Parmesan and Yohe [2] examined more than 1,700 species. More than half showed measurable changes in distribution and/or timing of their life cycles coherent with global warming. An analysis by Root et al. (2003) [3] of 143 studies "reveal a consistent temperature-related shift, or "fingerprint"—more than 80% of the species that show changes are shifting in the direction expected on the basis of known physiological constraints." Plants and animal populations are clearly feeling the effects of global warming.

Simply put, there is no real scientific debate: global warming from our activities [4] has altered biological and physical systems. Due to the timescales associated with climate processes and feedbacks, the effects will continue for decades or centuries. Thus, even if the human-induced emissions of greenhouse gases—the causes of the observed accelerated global warming—are stabilized in the very near future, our nation's wildlife will continue to feel those effects for some time to come.

MAJOR CATEGORIES OF CLIMATE CHANGE IMPACTS

(1) Sea and land ice meltdowns. According to the IPCC, average Arctic temperatures increased at almost twice the global average rate in the past 100 years. Satellite data since 1978 show that annual average Arctic sea ice extent has shrunk by 2.7% per decade. Temperatures at the top of the permafrost layer have generally increased since the 1980s in the Arctic (by up to 3°C). The maximum area covered by seasonally frozen ground has decreased by about 7% in the northern hemisphere since 1900, with a decrease in spring of up to 15%.

These changes in the Arctic environment have reduced the integrity of the region's unique terrestrial and marine ecosystems. Sea pack ice is disappearing, thinning, and moving further offshore from land, all of which tip the scales against wildlife that rely on this key habitat. Spectacled eiders (Somateria fischeri), a sea duck already listed as threatened under the Endangered Species Act, use large ice-free areas (termed polynyas) for foraging during the winter, and rest and sleep on adjacent ice edges strategically located over sea floor grounds rich in prey. Without such sea-ice roosting areas, spectacled eiders won't be able to easily reach their food sources. Rapidly changing ice conditions have forced ringed seals (Phoca hispida) to move and give birth to their pups in different locations—even under ice—making finding and catching seals a bigger challenge for the polar bears (Ursus maritimus) that depend on them for survival. With expectations that the Arctic Ocean will be largely devoid of summer sea pack ice later in this century, species such as polar bears, ivory gulls (Pagophila eburnea), walruses (Odobenus rosmarus), and the several species of ice-dwelling seals will find their habitat literally melted away.

Polar bears are especially dependent on sea ice as platforms for hunting the marine mammals that provide their nutritional needs. Because the necessary ice bridges linking land and sea have now been severed across wide areas, adult and young polar bears have starved and drowned. Some polar bears have resorted to cannibalism, leading scientists to remark that they are witnessing stressors unprecedented in decades of observation. The U.S. Fish and Wildlife Service has proposed listing the polar bear as threatened under the Endangered Species Act, a proposal which Defenders of Wildlife strongly supports.

On land, prospects are no better. Disappearance of permafrost has led to draining of Arctic wetlands, aquatic habitats used extensively by the breeding waterfowl that winter in the lower 48 states and support a multi-billion dollar sport hunting economy. Declining winter snow packs threaten terrestrial species such as the wolverine (Gulo gulo), a large relative of the weasel that relies upon snow drifts for maternal denning.

One key place where changes are especially visible is the Arctic National Wildlife Refuge in Alaska. The Arctic Refuge is the most important on-shore denning habitat for polar bears in the United States. As offshore sea-ice denning areas melt away, the Arctic Refuge becomes one of the last places for these polar bears to winter with their newborn cubs. The refuge's famed Porcupine caribou herd is also being

[1] Meta-analysis is a statistical method using multiple studies that examine similar factors and use similar methods. Conclusions reached through a meta-analysis are reinforced by the consistencies observed across multiple sources.

[2] Parmesan, C., and G. Yohe. 2003. A globally coherent fingerprint of climate change impacts across natural systems. Nature 421: 37-42.

[3] Root, T. L. et al. 2004. Fingerprints of global warming on wild animals and plants. Nature 421: 57-60.

[4] Intergovernmental Panel on Climate Change (WG-I) concluded that evidence of global warming is unequivocal, and that dramatic changes to the planet's climate are, with a 90 percent certainty, the result of human-generated emissions of greenhouse gases.

affected by global warming. Caribou (Rangifer tarandus) are departing their wintering grounds a month earlier and are still having trouble making it to the coastal plain of the Arctic Refuge in time for the earlier arrival of spring, when the most nutritious forage is available for their calves. Thus, the significance of the Arctic Refuge to wildlife is reinforced by the added threats from global warming.

(2) Habitat shifts. As the planet warms, the habitats required by particular species shift as well, typically northward in the northern hemisphere, upslope, and inland. Northern and elevational boundaries have moved, on average, 6.1 km northward and 6.1 meters upward each decade.

For some species already on the edge, these shifts could spell ultimate extinction. For instance, the Cheat Mountain salamander (Plethodon nettingi) is found nowhere else but West Virginia. Its entire range is just 935 square miles, spread across the high mountains of the east central part of the state from Backbone Mountain, Tucker County in the north to Thorny Flat, Pocahontas County in the south. The Cheat Mountain salamander is generally found above 2,600-3,500 feet. With one of the most restricted ranges of any salamander in the United States, and already listed since 1989 by the U.S. Fish and Wildlife Service as threatened throughout its range, this amphibian is extremely vulnerable. If global warming pushes it further up the mountains in search of a cooler environment, eventually it will find no place left to go.

(3) Heightened risks from invasive species, including disease. Rapidly changing environments increase the risk of invasive native and invasive non-native species, both of which can pose threats to other parts of natural systems they share. For example, the longer growing seasons from global warming have been implicated as facilitating unusually large and long outbreaks of spruce bark beetles (Dendroctonus rufipennis). In the past 25 years beetle outbreaks have resulted in the loss of an estimated two billion board feet of timber on the Kenai Peninsula and elsewhere in Alaska. Longer summers enable the beetles to complete one or more generations of their life cycle within a season, leading to exploding populations of this forest insect. In Guam, native wildlife is greatly threatened already from accidental introduction of the non-native brown tree snake (Boiga irregularis). Climate change will open new frontiers for such invasive species, and make conservation all the more challenging.

We know from studies of human health that rises in temperatures and increases in flooding are often associated also with a rise in certain infections and movement or spread of pathogens and disease vectors. Wildlife and fish are also susceptible to increases in disease risk. Such risk will become even more important as wild populations decline—a loss in numbers will increase demographic risks of extinction—as well as the impact of an increase in population density as animals move into the last remaining wild lands due to large-scale land conversions. This increased population density as well as increase risk of contacting an infected species or vector will magnify as new infections and disease vectors themselves spread into more regions with climate change.

(4) Rising sea levels. Projections of sea level rise from global warming range from 7 to 23 inches over the next century, according to the latest IPCC report. Accelerated melting of Antarctica or Greenland glaciers could raise sea levels by several meters[5]. Any rise will have negative consequences for some wildlife. Some islands used by the endangered Hawaiian monk seal (Monachus schauinslandi) could be completely underwater by century's end, overcrowding the remaining islands used for breeding and rearing of young and increasing the predation of seals by sharks. Other coastal species like the endangered Florida Key deer (Odocoileus virginianus clavium) depend entirely upon low-level barrier islands, and are especially vulnerable to sea level rise.

Essential habitats along low-lying coastlines are also at serious risk. Approximately 160 national wildlife refuges occur in coastal areas, including several refuges in New Jersey, Maryland, and Louisiana. Many of these refuges, like Maryland's Blackwater National Wildlife Refuge, protect coastal marshes that are only a foot or two above the current sea level. Even the lowest estimated rise in sea level over the next century will have profound effects on coastal wetlands, which are one of the most biologically productive ecosystems on earth. Coastal marshes also happen to be tremendous carbon sinks, and their loss will reduce their ability to absorb carbon and potentially release even more carbon dioxide into the atmosphere as the inundated marsh plants decompose.

[5] IPCC figures for the range in sea level rise are conservative. Ice cap and glacier melt, however, where the disintegration of ice shelves and lubrication of glaciers by meltwater speed up the flow of ice into the oceans, are more difficult to model.

(5) Longer droughts. Extended drought resulting from global warming poses an additional kind of threat to species that rely on already scarce water in arid environments such as the American southwest. For example, even in the best of times, survival can be precarious for desert bighorn sheep (Ovis canadensis spp.). Inhabiting steep, rocky terrain in the driest areas of the American southwest, they live in small groups isolated by miles of blazingly hot terrain. In southeastern California, rainfall has declined by as much as 20%, leading to drying of springs and disappearance of important food plants[6]. More than a third of the sheep populations that once lived in California's mountains have disappeared in the last century.

Less-arid regions face dramatic changes as well. As Defenders highlighted in our 2006 report, Refuges at Risk: The Threat of Global Warming, the prairie pothole region of the country is the nation's duck factory; its thousands of small lakes and ponds provide ideal habitat for breeding waterfowl. Over 50 national wildlife refuges, such as Medicine Lake refuge in eastern Montana, and Devils Lake Wetland Management District in North Dakota, have been established in this region to protect breeding bird habitat. Climate scientists predict that warmer climates in the northern prairie wetlands region will increase the frequency and severity of droughts—so much so that the number of breeding ducks in this region could be cut in half.

(6) Excess carbon dioxide. Often described as rainforests of the ocean, coral reefs support a dazzling array of creatures. But die-offs of corals, as much as 98% in some locations during the last 25 years, landed two coral species on the endangered species list. Staghorn (Acropora cervicornis) and elkhorn coral (Acropora palmata) form massive thickets, provide cover for numerous reef fish, and are essential for the health of entire reef ecosystems. However, warming ocean temperatures are stripping corals of the algae they need to survive, while carbon dioxide emissions are also turning the naturally alkaline oceans more acidic. Reefs subsequently turn into rubble because of lowering concentrations of carbonate ions, a key building block for calcium carbonate required by the corals. Threats from global warming to coral reefs have the potential to harm some of our most spectacular national wildlife refuges, including the Northwest Hawaiian Islands, Guam, Palmyra Atoll, Midway Atoll, and Kingman Reef in the south Pacific.

Guam's coral reefs are home to thousands of species of animals and plants, including hundreds of kinds of fishes and shellfishes. Fishes and other animals and plants taken from coral reefs are an indispensable part of the island's traditional diet. Tourists are attracted to the reef's abundant marine life and clear waters. Given other threats such as invasive starfish, pollution, silting, and other hazards, ocean acidification and other climate-change impacts only serve to increase the vulnerabilities of these key fishery habitats.

(7) Greater extremes in precipitation and/or flooding patterns. In natural systems, extremes can be just as important as the averages, and sometimes more so. The plains cottonwood (Populus sargentii) is the great tree of the American prairies; no other plant approaches the stature of this tree on the grasslands that sweep five hundred miles westward from the ninety-eighth meridian to the foot of the Rockies. This key tree species acts to provide wildlife habitat, shade, and streamside stabilization in the region. But the plains cottonwood is a flood-sensitive species that depends upon just the proper amount of precipitation (intermediate flooding). Not only is drought a severe stress on this trees, spring runoffs that are too powerful scour out the river bottoms used by the tree, washing away the sand bars and banks and any young trees.

The streamside salamander (Ambystoma barbouri) of Tennessee, Kentucky, Ohio, Indiana, and West Virginia is another example of a species that requires the optimal amount of precipitation, with too much rain just as stressful as too little. The salamander is most successful in first- and second-order streams that are seasonally ephemeral, that have natural barriers (cascades, waterfalls) that block upstream movement of predatory fishes, and that also have large flat rocks for laying their eggs. Increased flooding causes high mortality in this species, an amphibian with a total population size of only about 10,000.

(8) Disruptions to migration patterns. Some species are able to modify their behavioral patterns in response to environmental patterns, others are not. Climate change is expected to severely disrupt the timing and patterns of seasonal cycles and breeding migrations. Budding, flowering, pollination, seeding, and generation times of plants will change. Origins, routes, and destinations of migrating animals will be different. If climate change creates conditions that exceed the biotic limits

[6] Epps, C. W., D. R. McCullough, J. D. Wehausen, V. C. Bleich, and J. L. Rechel. 2004. Effects of climate change on population persistence of desert-dwelling mountain sheep in California. Conservation Biology 18: 102-113.

of these species, adaptation itself is at risk. For example, behavioral responses can be successful only if the animals are sufficiently mobile, their movements are not blocked, and they actually have an alternate place to live. For some species, this option is unlikely or even impossible.

Notably, we have very little information upon which to predict how climate-linked changes will disrupt the biotic interactions and inter-dependencies that have evolved at the community or ecosystem levels. The entire fabric of these systems is in jeopardy when species move, are extirpated from one site, invade others, or go extinct. We can expect surprises from these cascade or synergistic effects. Some of these surprises will detrimental to the interests of humans as well as wildlife.

(9) Direct effects of higher temperatures. Warming of the planet from greenhouse gases within the atmosphere is the ultimate trigger for all climate changes that we observe. However, regional expressions of elevated temperatures on the planet's surface from climate change can also directly impact fish and wildlife. For example, cutthroat trout (Oncorhynchus clarki) and certain other anadromous fishes have well-established climate sensitivities, and are susceptible to increases in the average temperatures of freshwater systems. Increasing ocean temperatures can cause gender imbalance in future generations of loggerhead sea turtles (Caretta caretta) because of their temperature-sensitive development. Studies also indicate that earlier nesting times of the sea turtle are directly linked to increases in sea surface temperature.

(10) More intense storms. Humans are by no means the only species to lose homes to the storms that are projected to be more virulent and to occur with greater frequency due to climate changes from global warming. Several imperiled species illustrate this particular vulnerability. Isolated populations of the threatened red-cockaded woodpecker (Picoides borealis), such as those found in parts of Florida, Louisiana, and other Gulf states, are susceptible to having their key habitats wiped out by more intense and frequent hurricanes. The West Indian manatee (Trichechus manatus), currently listed as federally endangered and proposed for downlisting to threatened status, experiences lower survival probability during years with more intense storms. Even our concerted action to shelter species for eventual recovery in the wild is put at risk. Recently, all or nearly all of the endangered whooping cranes (Grus americana) being held in a Florida captive propagation facility prior to release into the wild were killed by intense tornados. And it would be the ultimate tragedy if the recently rediscovered ivory-billed woodpecker (Campephilus principalis) loses habitat as a result of global warming.

A NATIONAL STRATEGY TO REDUCE GREENHOUSE GAS EMISSIONS AND HELP WILDLIFE THROUGH THE BOTTLENECK OF GLOBAL WARMING IMPACTS IS NEEDED

For many species, global warming is the greatest threat to their survival because changes in seasonal and weather patterns are altering their ability to respond environmentally or behaviorally. Species that are very specialized, rare, or those with very limited ranges, are less able to adapt to change and thereby more vulnerable to extinction. Others have been brought to the brink due to non-climatic stressors that already reduced their numbers, distribution and range, thereby making them less resilient to climatic change and more vulnerable to extinction.

Moreover, every species has a "tipping point"—a set of conditions which, if exceeded, will push it towards extinction. Some rare species may already have reached this point whereas others may soon follow without our efforts to intervene and save them. Wildlife managers must now explore new approaches and innovative strategies to manage the broader landscape as well as wildlife populations if we are to help species survive and adapt to these changes. Because impacts of climate change from global warming are already here and will continue, fish and wildlife need our intervention to navigate through this bottleneck in order to survive and reap the eventual benefits of the steps we take today to reduce greenhouse gas emissions.

A national strategy for combating the impacts of global warming on wildlife must consist of two key approaches. First, we must take immediate steps to reduce greenhouse gas emissions, to address the root cause behind climate change. Second, we must also craft responses now to help wildlife navigate through a looming bottleneck of complex effects caused by global warming. These two approaches are usually referred to as mitigation and adaptation. Both approaches are absolutely essential for our nation to frame its policy response as we build a comprehensive strategy to protect fish, wildlife, and other natural resources.

CONCLUSION

Impacts of climate change from global warming represent a truly global threat to our efforts to conserve and recover fish, wildlife, and other natural resources for

future generations of American citizens. As scientists and resource managers, we recognize the need to meet this challenge in a thoughtful, comprehensive manner. Where we have opportunities to reduce causes of climate change, we must support mitigation measures to reduce the levels of greenhouse gas emissions. At the same time, we must take adaptive steps to assist wildlife in navigating effects of climate change so that they can survive decades to a century of impacts still to come. The time to use both mitigation and adaptation is now, immediately. By addressing the needs of fish, wildlife, and entire natural systems, we also help ourselves. We and the generations that follow can continue to benefit from the remarkable diversity of economic, cultural, spiritual, and social goods and services provided by all terrestrial, freshwater, and marine ecosystems.

On behalf of Defenders of Wildlife, I want to thank you for the opportunity to share our observations and perspectives on this critical issue, and submit this testimony for the record at this hearing. It is no exaggeration to say that all work on behalf of conserving wildlife and its habitat, in North America and around the globe, is at risk now from global warming. We stand ready to work with this subcommittee and the rest of the Congress to develop solutions that will reduce greenhouse gas emissions and enable wildlife to survive until the benefits of emission reductions are fully realized.

Response to questions submitted for the record by Dr. J. Christopher Haney

QUESTIONS FROM THE HONORABLE MADELEINE BORDALLO, CHAIRWOMAN

Dr. Haney, in your view, what should the U.S. Fish and Wildlife Service be doing to prepare for global warming on national wildlife refuges and in its endangered species and migratory bird programs?

Refuges

First, the U.S. Fish and Wildlife Service (FWS) should consider the present and future impacts of global warming when developing objectives and management actions in the Comprehensive Conservation Planning (CCP) process.

Second, the FWS Division of Conservation Planning and Policy could coordinate efforts to assemble available knowledge on climate change in order to assist refuges around the country in obtaining current information and designing strategies to mitigate the worst of the anticipated effects. Also, the FWS should convene a panel of experts to assist refuges in developing adaptation strategies for coastal marshes and other habitats, including the prairie pothole region.

Third, in recognition that global warming will undoubtedly have a dramatic effect on many wildlife species and ecosystems, the FWS should take action now to minimize all non-climatic related stressors on refuge lands and wildlife. This would include mitigating for or reducing the harmful effects of fragmentation and roads on wildlife, among other things (boats, pollution, other incompatible uses of refuges, e.g.).

Fourth, global warming should be incorporated into all refuge environmental education and interpretation programs. Visitors should learn of how global warming and climate change are affecting the refuge's wildlife and ecosystems.

Finally, the expected effects of global warming and climate change should be incorporated into infrastructure design and planning, such as elevating buildings and other structural reinforcements near the coast.

Endangered Species

The FWS should incorporate global warming into recovery plans.

Migratory Birds

The FWS should carefully monitor migratory bird populations and design monitoring strategies that can detect changes caused by global warming. Waterfowl hunting levels should be adjusted accordingly.

The FWS should inform the Migratory Bird Commission of its monitoring and research on changes in migratory bird populations, habitats, and behavior and recommend changes in land acquisition strategies to conserve migratory birds carried out by the Commission.

Dr. Haney, what additional resources or tools will the Fish and Wildlife Service and National Marine Fisheries Service need to adequately prepare and address the impacts of global warming on wildlife over the next decade?

The following are some of the resources, tools, or approaches that the Fish and Wildlife Service and/or National Marine Fisheries Service (NMFS) could benefit from to better address climate change:

1) Fund permanently a new science center that focuses on wildlife and global warming to advise land and fisheries managers of adaptation strategies for dealing with the anticipated effects of climate change, that coordinates fish and wildlife monitoring strategies, and that researches effects of global warming on fish and wildlife.
2) The Departments of Interior, Commerce, and Agriculture should develop a national strategy for conserving wildlife in the face of global warming. Wildlife crosses jurisdictional and political boundaries and national level coordination is required to adequately conserve wildlife and assist wildlife in adapting to climate change.
3) Develop spatially-explicit maps of expected plant community changes (USFWS) or shifts in bathymetry, currents, and other marine attributes (NMFS). Such maps would be valuable as resource managers seek to anticipate and then minimize ecosystem changes.

Dr. Haney, you note that climate change is likely to disrupt wildlife migration patterns and that species which are sufficiently mobile, not constrained, and have alternate habitat available should be able to adapt their migratory behaviors to a changing environment. To your knowledge, has there been any research to identify how many wildlife species are not likely to meet these criteria?

Indeed, and given adequate opportunity and facilitation, some (but not necessarily all or even most) mobile species might be able to adapt to certain climate changes.

I am not aware of any research which has explicitly investigated which, how many, or what proportion of sedentary, non-mobile species are unlikely to be able to adapt. Until very recently at least, the most comprehensive forecast for impacts of climate changes on global biodiversity was made in 2004 (Thomas C.D. et al. 2004. Extinction risk from climate change. Nature 427: 145-148).

Analyzing distributions of 1103 species of animals and plants from various parts of the world, these authors showed that 15-37% are likely to go extinct based on the best projections of future climate change. Certainly many (but not necessarily all) of those species identified as vulnerable to extinction would be in the sedentary or less mobile category mentioned in your question.

QUESTIONS FROM THE HONORABLE DALE KILDEE

Dr. Haney, you noted in your testimony that climate change is likely to heighten risks from invasive species, including disease. Regrettably, the Great Lakes are all too familiar with invasive species. But if I understand correctly your testimony and the testimonies of other witnesses, the northern boreal forest areas surrounding the Great Lakes may be equally at risk.

1. How might we improve our present methods to screen and control for invasive species in the Great Lakes Region to temper the effects of a changing climate?

The over-arching objective for invasive species policy is to close off the pathways for entry while also maintaining active international and interstate trade.

One comprehensive means for doing so has been Executive Order 13112 (1999: 64 Federal Register 6183-6186). This Order also helped form the National Invasive Species Council (NISC) with representatives from the Departments of Interior, Agriculture, Commerce, State, Transportation, Defense, Homeland Security, Treasury, Health and Human Services, EPA, NASA, and others. The Order also established an Invasive Species Advisory Committee consisting of various stakeholders from states, tribes, universities, industries, and non-governmental organizations. The NISC created a National Invasive Species Management Plan which reviews approaches and authorities for preventing introduction and spread of invasives, minimizes risk of introductions via identified pathways, and identifies research needs and recommends measures for minimizing risks of introductions.

Major pathways identified for screening and controlling include: 1) Transportation-related pathways such as air, aquatic, and land transport vessels (airplane land gears, hull fouling, ballast water containers, packaging materials, solid wood

packing material, tourism, travel, and shipping); 2) Living industry pathways such as foods, pet and aquarium trades, bait industry, livestock and other animals, and trade in whole plants, seeds, and plant parts; and 3) Miscellaneous pathways including connected waterways, minimally processed plant and animal products (hides, trophies, feathers, logs, firewood, mulch, and straw), and ecosystem disturbances (rights of way, clearing, and damming). Any and all of these pathways can and should be tightened to prevent exacerbating the effects of climate change via greater risks from invasive species.

2. If both the surrounding uplands and the Great Lakes themselves are going to be threatened, should we be moving to a more comprehensive, holistic landscape planning approach to address invasive species? Might a new pilot program focused specifically on landscape approaches be helpful in testing and evaluating new methods?

Yes, a more comprehensive planning approach is much needed. One means of doing so would be to link Great Lakes upland and coastal planning for invasive species through a pilot program targeting one or more of the major pathways mentioned above, especially the ecosystem disturbances under "Miscellaneous," several of which must pass through the upland/lake boundary.

With respect to unintentional aquatic introductions into the Great Lakes the most critical improvement that now is actively being considered is an outright ban on ocean-going ships from going into the Great Lakes. After decades of ineffective responses to the well-known invasions caused by ballast water discharges and associated introductions from ocean-going ships it is time to put a stop to this traffic, which carries a relatively small amount of cargo at terrible environmental and economic cost to the Great Lakes region.

With respect to intentional aquatic introductions—that is human release of unwanted pet fish, live bait, aquaculture species and so on into Great Lakes connected watersheds—we must engage in pre-import risk screening for all intentionally imported non-native aquatic plants and animals brought into the United States. The current National Aquatic Invasive Species Act (NAISA) Senate bill, S.725, is a start—but it is not nearly strong enough. The provisions in S.725 need to be dramatically strengthened to require more comprehensive pre-import risk screening that is not limited to only "novel, not already in trade" species as in the NAISA bill. The NAISA bill would only screen a few species per year and give a green light to about a thousand other species.

As far as invasive plants and plant pests, both aquatic and terrestrial (e.g., including boreal forest pests), the Administration should support, strengthen, and finalize the current USDA Plant Protection and Quarantine proposal to dramatically strengthen our national pre-import screening of intentionally imported plants, known as the Quarantine 37 rule revision.

Finally, our USDA (now Homeland Security) and U.S. Fish and Wildlife port inspection offices are woefully understaffed and under-resourced. We need more and better trained inspectors to identify and block potential harmful invaders at our ports of entry.

QUESTIONS FROM THE HONORABLE PATRICK KENNEDY

Regardless of whether or not we take actions to control and reduce green house gas emissions, wildlife and wildlife habitat and the ocean environment are going to change and adapt, often unpredictably, to a warming climate. Consequently, we should take steps now to develop strategies to allow for the future conservation of biodiversity and the maintenance of a healthy and resilient environment.

1. Keeping in mind that any transition to a new "Green Economy" will take decades to achieve and that most Members of Congress will want to limit unnecessary disruptions of social and economic systems, can you be more specific on what practical types of adaptive management strategies we should consider to mitigate the negative effects of climate change on our collective wildlife and ocean resources?

Adaptive management strategies necessary for mitigating climate change must be drawn from existing, commonly-recognized conservation tools as well as new approaches that are not yet fully developed, this latter category encouraged through appropriate research and development supported by federal legislation.

For instance, adaptation strategies already available to us include reducing existing, non climate change-related threats to vulnerable species. Examples include reducing mortality, habitat protection (via economic incentives, conservation easements, land-use regulation), and restoration where appropriate.

Examples of new adaptation strategies that are not yet ready for implementation, although they could be essential in our toolkit for climate change adaptation include: 1) assisted migration, translocation, and/or captive propagation, 2) accelerated immunization for wildlife diseases (e.g., West Nile virus), or 3) genetic modifications and engineering methods for climate change adaptations.

Finally, public policies that encourage adaptations that jointly benefit humans and wildlife need to be identified and then implemented. One example of this would be when and where possible to facilitate coastal land uses that enable inward migration of both protected areas and regions of human settlement away from risk-prone zones.

2. Should we be doing more to re-evaluate our current policies for land use planning and public acquisition of land for wildlife habitat? Should we be adopting a broader landscape and ecosystem-based approach for protecting wildlife?

Of course we should be doing a great deal more. It makes no sense for each land management unit (e.g. park, forest, refuge) to develop wildlife adaptation strategies on their own. Greater assistance should be given to all the agencies and agencies should coordinate their management across jurisdictional boundaries. That is why Defenders believes a national strategy for assisting wildlife adapt to global warming is essential.

All land and natural resource agencies should consider the present and future impacts of global warming when developing objectives and actions when they craft management plans. Although these planning processes vary in strength, public input, and duration across agencies, each agency could and we believe should be given more incentives from Congress to target their planning for climate change.

Second, agencies should coordinate efforts to assemble available knowledge on climate change in order to assist their various operations around the country in obtaining current information and designing strategies to mitigate the worst of the anticipated effects. Also, agencies should convene a panel of experts to assist them in developing credible adaptation strategies for coastal marshes, the prairie pothole region, and other vulnerable habitats and systems.

Third, because global warming will undoubtedly have a dramatic effect on many wildlife species and ecosystems, the natural resource agencies should take corrective action now to minimize all non-climatic related stressors on fish, wildlife, and habitat under their jurisdictions. This would include mitigating for or reducing harmful effects of fragmentation and roads on wildlife, or disturbances from among other things boats, pollution, other incompatible uses of conservation land, and so on.

Fourth, climate change should be incorporated into all agency environmental education and interpretation programs. Visitors should learn of how global warming and climate change affect the nation's wildlife and ecosystems.

Finally, the expected effects of global warming and climate change should be incorporated into infrastructure design and planning, such as elevating and reinforcing buildings near the coast.

3. Finally, how might such ideas be applied to the ocean and coastal environment and the wildlife therein?

As mentioned above, far more attention needs to be directed at reducing risks (and thus costs to society) in the coastal zone. For public facilities, this could include better building codes for the extreme winds and waves expected from more intense storms (roughly analogous to earthquake coded-buildings in California). Certainly, public policy should not encourage (or at least reward) development that is sited in known risk zones. Some market-based solutions, such as much higher insurance premiums, might be appropriate.

One general idea that I have often heard from natural resource professionals is to re-orient the pattern of coastal land use so as to facilitate a gradual movement of everything (refuges, protected areas, human infrastructure) inland as sea level rises and risks from intense coastal storms increase. In this scenario, incentives for orienting land uses perpendicular to the coast would be favored over those that blocked such adjustments and adaptations.

QUESTIONS FROM THE HONORABLE HENRY BROWN, MINORITY RANKING MEMBER

1. Dr. Haney, in your testimony you state: "In Guam, native wildlife is greatly threatened from accidental introduction of the non-native brown tree snake". Are you suggesting that global warming is somehow responsible for brown tree snake infestation?

No, rather examples like accidental introduction of the brown tree snake can be expected to be more prevalent and more likely with climate change. As a recent report from our Military Advisory Board concluded, climate change acts as a "threat multiplier for instability..." For invasive, non-native species such as the brown tree snake, parts of our country once inhospitable to this species will become suitable for successful colonization as the climate warms. And the greater movements of people (including climate change refugees) and goods will act as vectoring forces to move more of these unwanted species around to places where they can be introduced.

2. You also tell us that Defenders of Wildlife is "dedicated to the protection and restoration of all wild plants and animals". Does that include brown tree snakes? (If it doesn't, what other species are not covered by this pronouncement) How much money has your organization donated in Guam to eliminate this terrible invasive species which has wiped out most native bird and lizard species?

As my testimony stated, Defenders is dedicated to protection and restoration of all wild plants and animals in their native habitats. Clearly, brown tree snakes are not native to Guam. I do not know the total budget our organization has devoted to addressing threats from invasive, non-native species over the past 5 or more years, but it is considerable. Much of our international program's efforts are devoted to limiting the risk of invasive species through monitoring of unregulated wildlife trade. Additional staffers from science, field conservation, and lands conservation also work to limit risks and threats from non-native species.

3. Dr. Haney, on Page 4 of your testimony, you correctly noted that the latest IPCC report finds that sea levels would rise "From 7 to 23 inches over the next century". Hasn't former Vice President Gore predicted 20 foot rises in sea levels? Who is correct, the IPCC report or former Vice President Gore?

Both or either may be correct. IPCC figures for the range in sea level rise are conservative. That is, they reflect a rise without any large-scale melting of ice caps and glaciers. However, ice cap and glacier melt, i.e., the disintegration of ice shelves and lubrication of glaciers by melt water, speed up the flow of ice into the oceans. But these are more difficult to model precisely due to more uncertainty in the parameters. Any accelerated melting of Antarctica or Greenland glaciers could raise sea levels by several meters, a figure in line with the predictions attributed to Gore.

4. You state that: "For many species, global warming is the greatest threat to their survival". Wouldn't that statement also be true if we were talking about a new "ice age"?

No. During the earth's ice ages, there were always warm zone refuges where plants and animals survived. But when the entire planet warms, there are no or many fewer (and much smaller) comparable cold zone refugia where species adapted to these conditions can survive. Also, the rate of warming currently experienced is notably greater than the more gradual temperature changes experienced in the earth's geological history. Moreover, past episodes of climate change on Earth occurred without the additional pressures on species from extensive human modifications. Therefore, species today have far less time and fewer places to make the sort of adjustments that they otherwise might be able to make.

5. Do you agree with the statement that: "Coal is the cheapest and dirtiest source of energy around and...if we cannot get a handle on the coal problem, nothing else matters"? Does your organization support a moratorium on coal-fired utilities?

Our organization does not specialize in nor have as its mission developing or promoting a national energy policy, the technology of energy, or the costs/benefits (economic, environmental, or otherwise) of various energy alternatives. As far as I know, Defenders does not currently support a moratorium on any particular energy source.

Furthermore, we stress that the nation cannot mitigate its way out of climate change impacts. By this I mean that while our treating the causes of climate change

is essential (e.g., through cutting back on emissions), we still have to deal with the effects of climate change. In other words, we must use adaptation in concert with mitigation for a national strategy to work. Our fish, wildlife, and ocean resources cannot wait, either, for the mitigation to work; they need our help with adaptation now.

6. Does your organization support reducing carbon emissions by 80 percent by 2050? How would you accomplish that goal?

See above. Our organization does not specialize in nor have as its mission crafting a national energy policy, the technology of energy, or the costs/benefits (economic, environmental, or otherwise) of various energy sources. Given our specific mission to protect native plants and animals in their native habitats, our organization is emphasizing adaptation as an essential complement to mitigation in order to solve the problems of climate change.

7. In response to a question during the hearing, you talked about the economic impact of hunting for migratory birds. Does Defenders of Wildlife support or oppose hunting?

Because we focus our efforts on imperiled species, the issue of hunting rarely intersects with our activities and projects. Defenders of Wildlife does not perceive hunting to be a conservation threat (at least as practiced in the United States). We also recognize the immense contributions that sport hunting and fishing make to land and water conservation in the nation, thereby reinforcing the success of our mission. Several of our staff and/or their families hunt, of course, including the Chief Scientist.

8. Do you or have you (or your organization) received any funding from the Pew Charitable Trust or the David and Lucille Packard Foundation? If so, please elaborate.

We have a grant from the Packard Foundation for policy analysis related to the Endangered Species Act. As far as I know, we do not have (nor have we had recently) any support from the Pew Charitable Trusts.

9. Are you currently a party to any law suit against the Department of the Interior or the Department of Commerce (or any of the agencies within these departments)? If so, please describe.

The following is a list of cases on which we are a party against the Department of Interior or Commerce:

- Defenders of Wildlife v. Gutierrez, No 05-2191 (right whale)
- Butte Environmental Council v. Kempthorne, No 05-629 (vernal pools)
- Stevens County v. DOI, No 06-156 (Little Pend Oreille - grazing)
- Defenders of Wildlife v. Kempthorne, No 06-180 (Fl black bear)
- American Bird Conservancy v. Kempthorne, No 06-02631 (red knot emergency listing)
- Cary v. Hall, No 05-4363 (African antelope)
- Communities fora Greater Northwest v. DOI, No 1:06-01842 (grizzly intervention)
- State of Wyoming v. DOI, No 06-0245J (Wyoming wolf intervention)
- Defenders of Wildlife v. Kempthorne, No 04-1230 (lynx)
- Conservation Northwest v. Kempthorne, No 04-1331 (Cascades grizzly)
- Defenders of Wildlife v. Kempthorne, No 05-99 (wolverine)
- Tucson Herpetological Society v. Kempthorne, No 04-75 (flat-tailed horned lizard)
- The Wilderness Society v. Kempthorne, No 98-2395 (National Petroleum Reserve - Alaska)

QUESTIONS FROM THE HONORABLE WAYNE GILCHREST

1. If paleo-records show that corals existed in the past under high atmospheric CO_2 concentrations, why is it a problem now?

A specific and arguably unique concern for this particular epoch of climate change is the speed with which it is occurring. Some-to-many species that might be able to adjust otherwise over very long durations of change simply cannot adapt fast enough in this recent climate change era.

In the case of relatively slow-growing corals, the sheer number of stressors from climate change may exceed their ability to adapt. For example, corals are subject to all of the following: 1) increasing sea levels with which their growth must meet in order to stay within the relatively shallow depths required by these marine species, 2) increased pollution from human coastal communities that were not present

in previous climate change eras, and 3) increased ocean acidification which compromises their calcium dependency.

2. Among the various effects of climate change to wildlife and the oceans, are there issues that are more pressing than the others? Why?

It is my professional judgment that low-lying coastal zones are among the most vulnerable sites to extreme impacts from climate change. (These impacts include long-term sea-level rise, but also more frequent, intense storms, beach erosion, increased salinity, disrupted navigation). My reasoning on the importance of this issue stems from the sheer number of climate change impacts, their severity, and the importance to natural resources (including many of the nation's commercial enterprises such as seafood and tourism) in these regions.

3. In the U.S., as plant and animal species migrate north and to higher elevations, what does that mean for the regions they leave behind? For instance, it has been said that some U.S. states that border Canada might actually benefit from the next few decades of climate change, but what will it mean for the states further to the South, and especially those on the coast?

My professional judgment is that some species will be able to move northward, and some subset of these will be able to thrive. Other species will not be able to move northward because the conditions apart from climate are not suitable for them. Two examples will illustrate. In Alaska, the east-to-west orientation of the Beaufort Sea will eventually block any and all terrestrial species from further northward movement. In the northern U.S. and Canada, the current agricultural bread baskets cannot survive moving north over the Canadian Shield because the soils there are unsuitable for farming.

To be sure, there will be both winners and losers under climate change. However, I not aware of any analyses which indicate that on a net basis, the "winnings" from climate change impacts will compensate for the "losses," even on a planetary scale (never mind for particular regions, like the U.S.). Some regions will experience disproportionately high impacts or losses. Just today (May 11, 2007), news accounts are reporting research that projects the eastern United States, including the South, will experience much higher summer temperatures than previously anticipated.

4. How do shifts in habitat range of plants and animals affect human interests such as agriculture or the spread of invasive species and diseases? How can we adaptively plan for such changes?

See answer to question #4, above.

5. The IPCC reports with 80% certainty that the changes in water temperatures, ice cover, salinity and ocean circulation are impacting the ranges and migration patterns of aquatic organisms. How will this affect management and use of these resources, and how can we prepare for any changes?

Because to some extent each species will react differently to climate change, the overarching preparation for climate change by the United States must embrace two goals: 1) mitigation of the causes behind climate change (emissions of greenhouse gases), and 2) adaptations to the effects of climate change.

6. In the Chesapeake Bay, we are losing marshland to rising sea levels. Can you talk about what is happening to coastal wetland areas in other areas of the country and what that is doing to their ecosystems and the local economies that depend upon these natural resources?

My specialty or area of expertise is primarily terrestrial wildlife. I would defer to other witnesses, especially on the second panel, who may possess greater familiarity with the regional differences in the response of coastal wetland areas to climate changes and/or the economic consequences of those responses.

7. What role do marshlands play in sequestering carbon? Is marsh restoration a viable alternative in carbon sequestration?

My specialty or area of expertise is primarily terrestrial wildlife. I would defer to other witnesses, especially on the second panel, who may have greater familiarity with biogeochemistry generally, and with marsh ecosystems specifically, for determining whether restoration was an effective alternative in carbon sequestration.

Current research indicates that carbon sequestration may not be appropriate everywhere, and indeed in some cases may make the problem of global warming worse. For example, carbon budget estimates for the Arctic indicate that increased woody vegetation (trees, shrubs) growing in high-latitude areas that are now

covered by tundra will actually accelerate warming (G. Bala et al. 2007. Combined climate and carbon-cycle effects of large-scale deforestation. Proceeds of the National Academy of Science 104(16): 6550-6555. This is because darker vegetation absorbs more heat, increasing surface temperatures, melting permafrost, causing less and shorter duration of snow cover, etc., thereby creating a negative feedback loop.

8. The latest IPCC report warns that ocean acidification poses a threat to coral reefs and shell-forming organisms that form the base of the aquatic food chain. But the report says more study is needed to determine the full scope of the threat. What do we know about the potential impacts to U.S. coastal ecosystems today and how quickly is our understanding of acidification improving? What can Congress do to improve upon this understanding? Do we know enough to act?

An arguably unique concern for this particular epoch of climate change is the speed with which the changes are occurring. Some-to-many species that might be able to adjust otherwise over very long durations of change simply cannot adapt fast enough in this era.

In the case of relatively slow-growing corals, the sheer number of stressors from climate change may exceed their ability to adapt. For example, corals are subject to all of the following: 1) increasing sea levels with which their growth must meet in order to stay within the relatively shallow depths used by these marine species, 2) increased pollution from human coastal communities that were not present in previous climate change eras, and 3) increased ocean acidification which compromises their calcium dependency.

One means to help corals better adapt to climate change impacts would be to reduce the levels of coastal pollution and nutrient loading that may be contributing to bleaching and other stressors.

9. What additional resources or tools will the Fish and Wildlife Service and National Marine Fisheries Service need to adequately prepare and address the impacts of global warming on wildlife over the next decade?

The following are some of the resources, tools, or approaches that the Fish and Wildlife Service and/or National Marine Fisheries Service could benefit from when addressing climate change:

1) Fund permanently a panel of experts to advise refuge and fisheries managers of adaptation strategies for dealing with the anticipated effects of climate change. Such panels would increase the scientific capacity of the FWS and NMFS with regard to climate change science.
2) Establish an interagency planning and coordinating mechanism, a National Council on Global Warming and Wildlife (or Marine Systems). Modeled after the National Interagency Fire Center and the National Invasive Species Council, the National Council on Global Warming and Wildlife (or Marine Systems) would develop a national strategy for addressing the impact of global warming on fisheries, wildlife, and ecosystems, with the express purpose of helping natural resources navigate the bottleneck of global warming impacts over the next century. This strategy should examine management issues common to geographic areas and threat type (e.g. sea level rise, increased hurricane frequency and intensity). Individual agencies and land management units could then coordinate their management activities with these national and regional goals and strategies. State strategies, particularly those set forth in state wildlife action plans, should address global warming impacts on wildlife and also be coordinated with the national strategy.
3) Develop spatially-explicit maps of expected plant community changes (USFWS) or shifts in bathymetry, currents, or other marine attributes (NMFS). Such maps would be valuable as resource managers seek to anticipate and then minimize ecosystem changes.

10. We've heard a lot about the polar bear and the petition to list the species under the Endangered Species Act (ESA). Opponents of listing claim that the effects of global warming are in fact unclear. What evidence is there that global warming is already having a dramatic effect on the species across its range? How will an ESA listing help polar bears?

There is no credible doubt that global warming and climate change have greatly decreased the extent of Arctic Ocean pack ice, the primary and essential habitat of polar bears. Indeed, since my testimony was delivered last month, the projections of pack ice loss have actually worsened, with estimates now that summer pack ice in the Arctic Ocean will disappear decades earlier than once forecast.

ESA listing will assist polar bears by giving the U.S. Fish and Wildlife Service more discretion over reducing other threats to polar bears, ones that are still within our control to influence and that will have immediate benefits while we await the results of our longer-term reductions in emissions.

11. To date, climate legislation has largely focused on reducing greenhouse gas emissions to reduce the threat of global warming. In your testimony you state that even if emissions reductions are achieved, there will be a period of at least 100 years where the effects of global warming will continue to be felt, and our national response should include adaptation strategies as well as emissions reductions. Can you explain how the earth will continue to warm even if we reduce our emissions?

Yes, all natural systems, including the Earth's atmosphere, experience a variety of time lags related to inertia in function.

With respect to greenhouse gases, some increased warming will continue because there is a lag between the atmospheric warming per se and the effects expressed in wildlife and ecosystems. For example, we currently are experiencing some effects from climate change from the emissions into the atmosphere that started long ago in the Industrial Revolution.

Another component to the lag times is that other, non-human emissions of greenhouse gasses will continue even as we halt or even reverse our own contributions. For example, much carbon is stored in Arctic permafrost and other locations which, although currently "locked-up", will be released into the atmosphere as the climate warms. These thresholds, tipping points, and negative feedback loops are a major source of continued warming even if man-made sources are controlled.

12. Your testimony portrays a dire picture for the future of wildlife in this country. What can be done to prevent species extinctions as the planet warms? What percent of the world's species are at risk?

Because to some extent each species will react differently to climate change, the overarching preparation for climate change by the United States must embrace two goals: 1) mitigation of the causes behind climate change (emissions of greenhouse gases), and 2) adaptation to the effects of climate change.

Until very recently at least, the most comprehensive forecast for impacts of climate changes on global biodiversity was made in 2004 (Thomas C.D. et al. 2004. Extinction risk from climate change. Nature 427: 145-148). This study Analyzed distributions of 1103 species of animals and plants from various parts of the world, and found that 15-37% of species are likely to go extinct based on the best projections of future climate change.

13. In your view, what should the Fish and Wildlife Service be doing to prepare for global warming on national wildlife refuges and in its endangered species and migratory bird programs?

Refuges

First, the U.S. Fish and Wildlife Service (FWS) should consider the present and future impacts of global warming when developing objectives and management actions in the Comprehensive Conservation Planning (CCP) process.

Second, the FWS Division of Conservation Planning and Policy could coordinate efforts to assemble available knowledge on climate change in order to assist refuges around the country in obtaining current information and designing strategies to mitigate the worst of the anticipated effects. Also, the FWS should convene a panel of experts to assist refuges in developing adaptation strategies for coastal marshes and other habitats, including the prairie pothole region.

Third, in recognition that global warming will undoubtedly have a dramatic effect on many wildlife species and ecosystems, the FWS should take action now to minimize all non-climatic related stressors on refuge lands and wildlife. This would include mitigating for or reducing the harmful effects of fragmentation and roads on wildlife, among other things (boats, pollution, other incompatible uses of refuges, e.g.).

Fourth, global warming should be incorporated into all refuge environmental education and interpretation programs. Visitors should learn of how global warming and climate change are affecting the refuge's wildlife and ecosystems.

Finally, the expected effects of global warming and climate change should be incorporated into infrastructure design and planning, such as elevating buildings and other structural reinforcements near the coast.

Endangered Species

The FWS should incorporate global warming into recovery plans.

Migratory Birds

The FWS should carefully monitor migratory bird populations and design monitoring strategies that can detect changes caused by global warming. Waterfowl hunting levels should be adjusted accordingly.

The FWS should inform the Migratory Bird Commission of its monitoring and research on changes in migratory bird populations, habitats, and behavior and recommend changes in land acquisition strategies to conserve migratory birds carried out by the Commission.

14. The melting of arctic sea ice is well known, but I was interested to read in your testimony that wetlands in the arctic are also being impacted—literally drying up. Can you explain this process and what are the impacts on migratory bird populations? What portion of U.S. birds relies on wetlands in the arctic?

The process of drying in Arctic wetlands occurs via two principal drivers. First, as the permafrost melts, the hard "pan" that underlies shallow wetlands in this region disappears, so the water simply drains away. Second, because much of the Arctic is essentially a desert with respect to annual precipitation, the marshy, boggy terrain was sustained historically because rates of evaporation did not exceed rates of precipitation. Now, however, the higher temperatures and reduced albedo (lower reflective properties in Arctic are due to ice/snow loss), this balance is disrupted, and more water is lost to the atmosphere.

Some migratory bird species in the U.S. (e.g., Spectacled and Steller's eiders) are entirely dependent on Arctic wetlands. For another set of species, most of the population breeds in the Arctic (e.g., the increasingly threatened Red Knot). Finally, for yet other species, a large proportion breeds in the Arctic (e.g., Northern Pintail).

Ms. BORDALLO. Thank you very much, Dr. Haney.

Consistent with Committee Rule 3[c], the Chairwoman will now recognize Members for any questions they may wish to ask the witnesses, alternating between Majority and Minority and allowing five minutes each for each Member. Should Members need more time, we will have a second round of questions.

Before I recognize the first Member of the committee or the Ranking Member, I wish to ask a couple of questions myself. The first question is to Mr. McKibben. I want to thank you and all the witnesses for your excellent testimonies this morning.

In the report on your latest efforts, Mr. McKibben, to organize peaceful protests for action to address climate change, you note that people across the country are concerned, informed and energized, but are there specific action items other than the goal to reduce carbon emissions that they are calling for? Does protection of wildlife and wildlife habitat resonate as a priority?

Second, oftentimes critics of climate change label people concerned about the issue as alarmist or naíve about the economic and social costs of addressing the challenge. In your estimation, Mr. McKibben, are the people who recently demonstrated around the country uninformed about the tradeoffs, or are these people aware of the scope and the complexity of the problem?

Mr. MCKIBBEN. Those are very good questions. First in response to the question of whether or not people take wildlife and habitat seriously as a part of this phenomenon, I think the answer is very clearly yes.

Around the country, among other things, as we have looked at these photographs one of the things we have noticed and everybody who took part in these demonstrations, one of the things they did was upload that day to our website a photograph and so there are now 1,400 or something of these pictures rotating through in a

slide show on that website. You have many of those pictures from your districts in front of you today.

One of the things we noticed was that there were an awful lot of people in polar bear costumes at various places around the country. Another thing we noticed, and I hope you will get the chance to go on the website and click the video that shows maybe the single most beautiful of all these demonstrations, a group of scuba divers underwater off the Florida Keys with that same banner, 80 percent by 2050.

In response to the question of particular mechanisms that people are hoping to—the most important thing we think at the moment is for Congress to finally set real and long-term targets with a detailed agenda to get going quickly on them.

The reason for that is that having done that will send the necessary signal into our economic community, enough of a signal that carbon will no longer be a free good in the atmosphere, that the series of investment decisions and things that follow for the next 40 years will begin to have a kind of virtuous effect. Certain things will begin to happen.

Now, we know what some of the things are that cannot happen if we are ever to meet that goal, and chief among them and one of the things that people brought up at a number of these protests was the need not to put on-line these 150 coal-fired power plants in one stage or another of being on the books in this country. I think that that was a very clear consensus.

As to whether people are either naíve or alarmist in these demonstrations, I think the answer is clearly no. In fact, what has been very nice is to see the kind of naívete begin to disappear, the idea that somehow the rules or the laws of physics and chemistry might not apply to the United States or that we might be able to avoid dealing with the molecular structure of carbon dioxide; that that naíveté is finally beginning to disappear.

Far from being alarmist, I think people are exceedingly realistic. They know that this will be a difficult job in order to wean our economy away from fossil fuels. They are also, however, confident, and I think confident in a very American way, that it is possible to put ourselves to this task and accomplish a good deal.

One of the things that we heard over and over again was a kind of expression of dismay at the almost un-American timidity of those who say that it is impossible to deal with this problem or that we have to go exceedingly slowly or that it will put us out of business or whatever it is.

We have a problem. People understand that we have a problem, that that problem derives from basic laws of physics and chemistry and that we better roll up our sleeves and get to work solving it.

Ms. BORDALLO. Thank you. Thank you very much, Mr. McKibben.

I think the Chair now would like to go ahead and recognize the Ranking Member if he has questions for the witnesses.

Mr. BROWN. Thank you, Madam Chairman.

To continue that same dialogue, Mr. McKibben, I know we talked about what Congress can do to get us through this problem. We are talking about cutting I guess the emissions by 80 percent by 2050 or somewhere thereabouts.

What can we do as individuals? I mean, it is easy for Congress to mandate. Should we mandate that everybody has one car and it takes 40 miles to the gallon or maybe it is all electric, or you can only drive with four people in the car? Maybe we all should go to mass transit.

I mean, it is limited what the Federal government can do and so we have to be careful of what we ask the Federal government to mandate on our quality of life.

We mention about coal powered, and we recognize there is some abuse, but we recognize too that industry has been doing a lot, putting scrubbers in and converting some of the byproducts into other materials and so I know industry is working collectively to try to do something. I don't know about mandating them, how that might work, if we could develop tax credits or some other incentives to get us through that.

Tell me what we as individuals could do? In fact, as I have heard the testimony from Dr. Lawler about the forestry, I was hoping he would bring in some injection of some kind of a reinforcement of what we can do proactively as citizens. Maybe we could plant more trees or do something else to help with the climate change rather than trying to address the issue through a second person.

Anyway, I am anxious to hear either one of your comments on that.

Mr. MCKIBBEN. Let me speak first. I think that the question about intrusive Federal mandates is a good one, and I think that it is one of the reasons why Congress would be well advised to try to set an overarching architecture for what is going to happen over the next 50 years so that then to some degree anyway the market could do the work.

If you set a cap on carbon and begin to rachet it down, that signal will spread throughout the economy, and we will begin to get some of these changes that we need.

The example that you give of scrubbers on coal-fired power plants is a very good example. That sort of thing is what happened 20 years ago for sulfur and nitrogen compounds and is one of the reason we have begun to see those declines.

Nothing like that has been done as it regards carbon dioxide, the global warming gas, and as a result those emissions in our economy continue to increase one percent a year, year after year after year, despite the scientific wisdom that we have come across.

Now, there are important mandates that need to be made that only Congress can make that will begin to accomplish some of these goals. You mentioned some of them. Clearly we need an increase in automobile mileage standards. The average car coming off the assembly line today gets poorer gasoline mileage than the car that Henry Ford was pulling off his assembly line in the 1920s and the 1930s.

That is pretty shocking, and it is not a good sign at all. We have the technology to easily produce cars that get much better than the 40 mile per gallon figure that you estimate, and we should get to work on it.

If we begin to make large-scale, targeted plans for the future then some of these changes will begin to make themselves and lessen some of the need for directed mandates, but that is not to

underestimate the degree of work that it is going to take in order to accomplish this transition.

Mr. BROWN. Let me interject. I know my time has just about slipped away.

On the second panel we have Dr. Sharp, and he is going to testify in his written statement that manmade levels of carbon dioxide are only three percent of the global carbon cycle.

Do you agree with that number? If so, are you suggesting reducing the manmade carbon dioxide by 80 percent? How are we going to handle nature's influence?

Mr. MCKIBBEN. I do agree with that number, and I am suggesting that.

As I think the rest of the panel will indicate, the natural world was fairly well balanced for carbon before the injection of anthropogenic CO_2 in the wake of the industrial resolution. It is that added increment that is now piling up in the atmosphere and causing these changes.

Since we are unlikely to be able to legislate away volcanos, it probably makes more sense to legislate those things that we can control, our own actions.

Mr. BROWN. I know my time has expired, but I know the influence that we are going to have from the emerging nations like China and India with all of their unregulated power plants or whatever.

There is going to be an influence, and somehow or another we have to get a national policy directed and be careful of how we address just the United States.

Thank you, Madam Chair.

Ms. BORDALLO. Thank you. Thank you.

The Chair now would like to recognize Mr. Kildee, the gentleman from Michigan.

Mr. KILDEE. Thank you, Madam Chairman.

Ms. Medina, I shared dinner and conversation with the Russian Ambassador last night, and he and your 10-year-old son would agree on the polar bear should they get a conversation.

The Russians recognize that the polar bears are moving further south because of the climactic changes taking place now. In their own history, that is something new also. It was very interesting. Out of the mouths of young people has perfected wisdom.

Dr. Haney, a question directly to you, but anyone may answer this. The Great Lakes, when I live in Michigan, have already been affected by invasive species brought about by human activity. We have the zebra mussel, which is very costly to us; the emerald ash borer, which is devastating our ash trees.

What effects might we expect with climactic changes? What effects will it have on invasive species in the Great Lakes, the introduction of invasive species? If you want to go beyond that on the lake levels and forest health and agricultural health?

Dr. HANEY. Well, there could be several. One of the expectations of global change generally is that there will be more movement and transport of peoples. We have already seen that through other kinds of globalization.

So there is a high likelihood that more nonnative species are simply going to get moved around from one place to another, giving

them the opportunity to establish. That is because we are more active all around the planet.

Another potential impact on the Great Lakes is that the changing temperature of the water will make the Great Lakes more acceptable or suitable or vulnerable to species that aren't native to that freshwater ecosystem, so whereas 50 years ago they might not have been able to thrive there they can today.

Another potential impact, although I realize this is more longer term and somewhat speculative, is that as the planet's freshwater resources get redistributed the Great Lakes are going to look very appealing as a place essentially to mine fresh water.

Any of those things can act to—and if increased ships come in from other places to take out the freshwater, they are going to bring in their ballasts or on the hulls of the ships new species that might have the potential to establish themselves.

Mr. KILDEE. The two largest bodies of freshwater in the world would be our Great Lakes and Lake Baikal in Russia. There was always a temptation to draw from those freshwater bodies I know.

I think you had a response also?

Dr. ROOT. I actually was at the University of Michigan for 14 years, and I did a bit of studying on how global warming was going to affect the state. The lake levels are indeed going to drop, and that is going to hurt the fish nurseries that occur around the edges.

The other thing it is going to do is it is going to increase the pollution content of the lakes because the pollution is not going to be going out, the heavy metals and the like. Right now you can eat whitefish what, once a week from the Lakes. You probably will not be able to eat any from the Lakes after there has been quite a drop in the lake levels.

I just wanted to also agree with Chris in saying that the increase in population in Michigan is something that they are really quite concerned about because people are going to be moving up to Michigan because of the water.

Thank you.

Mr. KILDEE. Dr. Lawler, you had some response also?

Dr. LAWLER. Yes. I was going to give you potentially one or two examples of invasive species changing with climate change.

One is the mountain pine beetle in the western United States, which can devastate large stands of pine. It has moved up into pines that it didn't used to work on, it didn't used to affect, white bark pine at high elevations.

In so doing, it has had sort of a cascade of ecological effects. By knocking out those pines, by killing off those pines, it devastates one of the winter food sources for grizzly bears and so it can have an effect on the pine trees. It can have an additional effect on grizzly bears.

That is sheerly due to warming, so as the temperatures warm the beetle has been able to move up slope. It has been able to move into trees it hasn't been in before. It is also moving northward into Canada, and there is fear that it will connect to pine populations that go across northern Canada, and it may even make its way into the eastern U.S., so invasive species will move as well as our basic wildlife species.

Mr. KILDEE. So we are already seeing that?

Dr. LAWLER. We are already seeing changes in invasive species.

Mr. KILDEE. I thank you very much.

Thank you, Madam Chairman.

Ms. BORDALLO. Thank you. Thank you, Mr. Kildee.

The Chair now recognizes Mr. Gilchrest.

Mr. GILCHREST. Thank you, Madam Chairman. Welcome to all the witnesses this morning.

I was going to say something to my colleague from South Carolina, and maybe even you can give us some recommendations on novices reading good information about the scientific data collected over decades dealing with this issue unbiased from any industry or political source. I think that it is vital for us to act boldly and not be dysfunctional with an issue that is so potentially catastrophic.

The comment I wanted to make was that I learned recently an interesting little tidbit. Sometimes these little tidbits give us insight. We put more CO_2 into the atmosphere from burning fossil fuel in any one given year than it took nature a million years to lock up that same amount of CO_2. I tested that tidbit any one of a number of times, and it has always proven to be accurate.

My colleague, Roscoe Bartlett from western Maryland, made an interesting statement/insight into this issue, a clearer image so we could look at it. He said if you had a scale with 1,000 pounds on each side—this is in reference to we are contributing three percent of the CO_2. If you have a scale with 1,000 pounds on each side and it is balanced, you add one pound to one side, which is extraordinarily tiny, and it goes off balance. To some extent, that is what we are doing.

The other thing, we are talking about environmental concerns here, and there are many environmental concerns, but it is also an economic issue. As long as we are not energy independent, our economy will be virtually sluggish in the international global marketplace.

New, innovative, bold technology will rise the U.S., not only becoming a green nation, not only leading the world in this issue, but we will have the innovative technology that the world will want.

The last thing is national security. We get our fuel source from very, very unfriendly, unstable areas of the world, so if we look at the issue of climate change it is environmental, it is economic, and it is national security.

We have a Climate Stewardship Act that I will not go into much detail today, but it does push for that reduction by 2050 to 70 or 80 percent below 1990 levels, and if you look at that a little bit further you will see that the scientific data is clear that we do not want to go beyond that threshold of 450 or 500 ppm of CO_2 because then we are not sure what the climate change is going to be, the catastrophic events that will occur after that, not to mention what is happening right now with the piling up of CO_2.

The question I have, and I have three questions if I could get into them. Maybe we will have a second round. I apologize for my soap box. If we look at the Canadian and the U.S. border, what do we see as changes there? The Chinese-Russian border? What do we see as changes there? Coastal areas like Maryland, the Chesapeake Bay, and the coast area of South Carolina, for example? Southern regions like Brazil, Central America?

Can you give a quick response as to wildlife in those regions? I know you need about a three hour timeframe. I have probably a minute and a half left.

Dr. LAWLER. I can give you just some stories that relate at least to my research.

Some of the biggest changes in wildlife will likely be in the tropical regions, particularly in terms of sheer numbers of species. That is where the most species are. The changes even with my model, some of the most drastic changes show 300 to 600 species changing position in certain areas. That is from a reduced set of species, not all the species that are there.

So the biggest changes will likely occur in the tropics for the reasons that, one, there are more species, and, two, that is where some of the biggest climate change is expected to be seen, the tropics and the high latitudes.

In terms of borders, some interesting things will happen. Species will move across borders. Sometimes diseases will move across borders. Invasive species, as we were talking about, will move across borders. Also species that we care about and national treasures may also move across borders and no longer be ours, so to speak, so those are changes that we will see in terms of wildlife at borders.

The disease might be the most disturbing to me I think, seeing new diseases come from countries to the south and diseases moving into countries to the north.

Mr. GILCHREST. Dr. Root?

Dr. ROOT. I have no time left.

Mr. GILCHREST. Sorry.

Dr. ROOT. May I answer, Madam Chairwoman?

Ms. BORDALLO. Yes.

Dr. ROOT. Thank you. Thank you.

One of the main things that I think is going to be going on with species is that they are shifting their ranges. They are going north in North America. We have already seen that. I have seen it in Michigan. The work that I did in Michigan was looking at the Upper Peninsula, and there was a very strong shifting that is going on.

Actually that is wrong. Some of these species are shifting up. Others are not. That actually is the concern because you are going to have this tearing apart of the biotic interactions that we have right now, kind of the balancing of nature. When you tear apart these predator/ prey relationships, what is going to happen? The prey is going to go up in abundance.

Now, what happens if that is a bug that eats our agricultural crops? We will be concerned. What if it is a bug that pollinates our agricultural crops? That will be wonderful. So what we need to do is figure out how each of these species is going to be moving because they are going to be moving differentially.

Mr. GILCHREST. Thank you, Madam Chairwoman.

Ms. BORDALLO. Thank you. We could have a second round, Mr. Gilchrest, if you would like to ask further questions.

The Chair now recognizes the gentleman from Rhode Island, Mr. Kennedy.

Mr. KENNEDY. Thank you, Madam Chair.

I want to associate myself with the remarks of the gentleman from Maryland on his work. He has been outstanding on issues of ocean protection, and it has been a pleasure working with him to try to put protection of our nation's oceans and the world's oceans on more of a priority.

In that regard, we have tried to focus on looking at all of our oceans policy as it is affected by each of our agencies, and it seems to me when we are talking about this is that we have to look at a global kind of agency to start to bring together this global strategy of how we are going to look at this. If it is going to affect every nation, every nations' policy is going to be impacting this.

What are you all proposing in terms of how the United States can lead in the way of setting up more as the United Nations effective at all through their efforts as the World Bank? World Bank is obviously a great tool for when it is lending. It lends to these developing nations on certain criteria. It can have an enormous impact if those criteria include following the dictates of certain developmental criteria and so forth and so on.

I mean, we have to think a lot bigger than our little corner of the earth, because of course this is not us. This is the whole world. What are we doing? What can we do to propose something that establishes something bigger?

We have the World Bank, but it is really controlled. We have a managing control of it. I mean, it is really great. We have other institutions that we have great influence on. I mean, these are the kinds of things we need to have strong recommendations from groups like yours in order to make a profound impact. I mean, that is what we need from all of you.

In terms of getting a sense of what the real budgets are going to need to be in place in order to manage these changes, we are going to need more specifics. I mean, it is not enough just to say we are going to need more in the budgets for managing fish and wildlife.

I mean, we are going to need to know what instructs us in terms of what the order of magnitude is going to be in terms of managing the Bureau of Fish and Wildlife and how is that going to instruct what our budget is going to be.

You know, give us some more tangible things to go on here because we need to come up with specifics. It is not good enough right here for us to talk about it because we all get it. I mean, I appreciate the fact that you don't think that we are doing enough, but, quite frankly, we are reacting to the American public.

When you are saying you have trouble getting 1,000 people together for a march and it has taken this long for you to get it and you are the first person to come up with a book in 1987, frankly that points to the problem. The American people haven't been.

We are just a reflection of the American people, and the fact that they haven't been screaming about this has been tragically the reason why their democracy hasn't worked for them is because they haven't demanded more from their representative government.

Until you give us some specifics in terms of what you need us to do, we are going to be floundering out here in terms of just talking about it. I don't think that is going to do us a lot of good.

Mr. MCKIBBEN. Let me respond to the larger question and then I think to the more detailed budget questions.

You should know that Americans now are screaming for just this kind of action.

Mr. KENNEDY. I understand that.

Mr. MCKIBBEN. It will be interesting to see what kind of response that gets. Your question——

Mr. KENNEDY. Let me just say this. This is not to me calling on me for global change. I don't get that many calls. I can honestly tell you, I do not get that many people calling my office on environmental——

Mr. MCKIBBEN. We will do our best to make sure that you get more.

Mr. KENNEDY. I have a 100 percent voting record on the environment, so it is not as if——

Mr. MCKIBBEN. That may be why they don't call you. This question goes directly to something that Mr. Brown asked too, which was a very wise question, which is how we get the entire world involved in this situation.

Of all the reasons that it is important for this Congress to take dramatic steps to begin reducing American carbon emissions, perhaps the most important is that it will give us some credibility again in the international negotiations that need to go on quickly in order to produce a worldwide response.

The United States and China in particular have served as each other's enablers for the last six years in making sure that no action takes place. Since we are the historical giant in contributing carbon emissions to the world, it will be once you all do something about this that you will be able then perhaps—perhaps—to engage China and India and the rest of the developing world, but that waits on credible action in this country, and that is something that people increasingly understand.

Mr. KENNEDY. No question. We have to have our own credibility. We have to walk the walk before we talk the talk. I understand that, but it would be helpful to begin to understand that we need to get some specific recommendations.

This hearing is about trying to decide what our authorization should be in terms of a bill and what projected budgets we need for the Bureau of Fish and Wildlife, for example, so we need specifics.

Ms. BORDALLO. Ms. Medina?

Ms. MEDINA. If I could jump in?

Ms. BORDALLO. Yes.

Ms. MEDINA. I am sorry to keep extending this time, but I think this is an excellent question, Congressman Kennedy.

I want to say first in reaction to your question about whether the public is behind you on this, I guess I as a citizen and as a member of a group that activates citizens that sometimes leaders have to lead and that this is a difficult problem that is complex.

We, the public, I think are looking to you as our representatives to lead and to take the steps that we may not as one individual in the public be able to take in terms of policies.

I think what you are seeing, though, is that the public cares more about this and is doing things like buying those lightbulbs

and hybrid cars and using their consumer power to change their behavior, and hopefully with more education and more leadership from our leaders in Congress people will be able to do more.

That also means turning that leadership outward toward the rest of the world. I just attended a symposium in New York last week at the U.N. on whale conservation. There is a little known body called the International Whaling Commission that governs all commercial whaling, and it actually has a moratorium right now in effect on commercial whaling, which has been totally undermined by certain whaling nations who whale in the guise of science.

I believe there are international institutions out there, and there are a number of them dealing with Arctic species, that cut across international borders and require international cooperation now, and what you as our leaders can do is reenergize those bodies to get to work and to do the hard work of figuring out how to take actions right away to conserve these species.

You don't have to invent anything new. There are lots of good ideas out there. I have heard one that I particularly like from the Progressive Policy Institute that calls for an E-8, an environmental group of eight large nations that might be able to come together and bring some of the most powerful nations and some small nations too into a more limited or small debate to begin to address some of these issues.

I believe, Congressman Kennedy, there are lots of great ideas out there and that it is difficult to sort through them all, but that with political will and leadership by the Congress we can get it done.

Ms. BORDALLO. Thank you. Thank you very much, Ms. Medina.

The Chair would now like to recognize the gentlelady from California, Ms. Capps.

Mrs. CAPPS. Thank you. I congratulate you, Madam Chair, on putting together such an excellent panel, and I thank our witnesses for really doing a fabulous job today.

With just five minutes, I want to divide the time in two and ask more specific questions to Dr. Haney about Hawaiian monk seals and to Dr. Root about migratory birds.

So if I could start, Dr. Haney, last year President Bush designated the northwest Hawaiian Islands as the largest national marine monument in the world. These islands are the chief breeding and resting places for rare Hawaiian monk seals.

Less than 50 years ago, a group of low lying islets called the French Frigate Shoals covered about 110 acres. Today only about 38 acres are left. What should we expect to happen to these Hawaiian monk seals if these beaches continue to disappear under rising seas? Perhaps you want to include other wildlife as well.

Dr. HANEY. Well, that is an excellent question, Congresswoman, and it illustrates very well some of the unintended consequences that can happen when we think that a species might just be able to move to a new site and be fine.

The Hawaiian monk seal has been gravely threatened for some time. It has had a very small population for the better part of the last century, and the fear, the specific concern, about the Hawaiian monk seal is that as these low lying islets, coral atolls and beaches, as they become inundated the seals may move to larger islands.

But in so doing they subject themselves to potential predation by sharks, so they have really moved out of their comfort zone, the place where their prey, their resting sites, their haul out sites is all toward their welfare and into a kind of a new scenario.

That illustrates the dilemma of managing as a nation for climate change. It is important to keep in mind that we need to think in two tracks. We need to treat the emissions.

That is something that we have to work on globally, but when it comes to mitigating the effects now that is something that we have in our control as a nation to do, and it is what Congressman Kennedy referred to as what sort of tools do agencies need.

Mrs. CAPPS. Right. Thank you so much. I know we could go on about this, but you highlight something which we need to focus on, and I hope we can in the Subcommittee, which is adaptation strategies. That is a whole other topic, I know.

I want to also touch on migratory birds. Dr. Root, Dr. Haney noted in his statement that wetlands in the Arctic are literally drying up and that this could have a significant impact on migratory birds.

What portion of U.S. birds relies on wetlands in the Arctic for part of their life cycles, and do you agree that the loss or change of Arctic habitat will have or maybe already does have an overall negative impact on migratory birds?

Dr. HANEY. For some species the entire world population is in the Arctic, and for some of them the entire population is essentially in Alaska. A spectacle lighter would be an example, some of the other sea ducks.

You know, other waterfowl species use lots of states. They use the Canadian prairies, the U.S. prairies and Alaska, and what is interesting is that, for example, northern pintails, when the prairie states are dried up they just keep going because historically they have always been able to find wetlands more reliably further north because essentially even though the Arctic is a desert, the evaporation is so low that the wetlands in the permafrost keep the water from draining away.

Mrs. CAPPS. Right.

Dr. HANEY. It maintains a nice balance. Now we have disrupted that. The permafrost is melting. Those wetlands are draining. The heat has gone up, so the water is disappearing into the——

Mrs. CAPPS. Is this already happening?

Dr. HANEY. It is already happening. In fact, there was a really interesting study—I don't even know if it is out in print yet; it was in press the last time I looked—documenting a 30 to 40 percent reduction in Arctic wetlands.

So depending on which kind of migratory bird we are talking about, the entire population may be dependent upon it or 80 percent or 30 percent, but to some extent these are the key nursery areas for a billion dollar sport hunting industry that is very important in this country.

The birds that we see in the wintertime, many of them come from the far north.

Mrs. CAPPS. Thank you.

Do you want to add?

Dr. ROOT. Because I didn't really know the percentages that you asked me for, but I did do a study of the prairie pothole region, which is around Minnesota and into Canada, and 50 percent of our wild waterfowl actually breeds in that area.

I have done a study that shows that if we go up to and above three degrees C from preindustrial that that is going to drop to probably about 12 percent because it is not going to have the water and the light to be able to have the nest there. As Dr. Haney was saying, they fly up. They continue to go, continue to go. They are not going to be able to find anything.

The other migratory birds that are not going all the way up that are actually stopping in Michigan and things like that, they also are having quite an effect already. We have seen a lot of them already moving north, and that is a concern in the northeast because there are three different species of warblers that feed on spruce budworm caterpillars, and they have already shifted up.

We are already seeing stresses on trees because the caterpillars are going up in abundance, so there really is this connection between predator and prey. It is really quite important.

Thank you.

Mrs. CAPPS. Thank you very much.

Ms. BORDALLO. I would like to thank the gentlelady from California and remind the Members here that we will go to a second round of questions. However, we do have a second panel to hear from so it is up to you if you wish to ask further questions.

I have one for Dr. Root. Regardless of whether or not we take actions to control and reduce the greenhouse gas emissions, the consistent theme running through all of your statements this morning is that wildlife and wildlife habitat are going to change due to the warming climate.

Can we be more specific on what practical types of adaptive management strategies we should consider to mitigate the negative effects of climate change on wildlife? Should we be doing more to evaluate our current policies for land acquisition? Should we be adopting broader landscape approaches such as developing migratory corridors to allow wildlife to access suitable habitat?

Even if it is remotely possible that all the current global climate change models are wrong, would it not make more sense to implement these concepts now to enhance our conservation of wildlife and preserve other valuable ecosystem functions? Dr. Root?

Dr. ROOT. Thank you. I would actually like to add one comment to Congressman Gilchrest's list that you gave as far as economic issues, national security issues. I actually also think that this is an ethical issue, and I think that we as one species do not have the right to cause the extinction of other species.

So getting to your question, it is exactly right. How can we do something to help these species? Something that California has come up with is a nonsolid border preservation so that as things are moving the area that is actually being preserved goes with the species.

Now, where we have done that is along the coast because we don't know where the coastline is going to be, so we don't want to have a set definition. What is happening is it is going back and forth.

That is easier because it is on the coastline, but I do believe that what we need to be doing is something very crazy, something like that, because we don't have land around to say OK, we are going to save this, and we are going to save this, and we are going to save this.

If we could have a preserved area that goes north to south that would be great instead of doing it east to west, but we don't have the land so if we can somehow hook onto the species instead of the land and help the species going as they are moving, I think that may be one way.

I actually think that that could work in other countries, too. It is not easy, but I think it could work.

Ms. BORDALLO. Thank you. Thank you very much, Dr. Root.

Mr. Brown, do you have follow-up?

Mr. BROWN. Thank you, Madam Chairman. This has been a very interesting discussion, and I certainly appreciate the panel being here.

I think we need to define exactly how we are going to be able to reduce this two percent or get down to 80 percent in 45 years. I know the population of the world today is about what, 6.5 million?

Dr. ROOT. Billion.

Mr. BROWN. Billion, right. 6.5 billion. In four to five years, what do you think the population of the planet will be then?

Dr. ROOT. Eight billion.

Mr. BROWN. Eight billion?

Dr. ROOT. The more I think about it, nine billion.

Mr. BROWN. Nine billion. That is going to be a major I guess task that we are going to have to deal with is how are we going to be able to fit in three billion more people in that period of time at the same time as we try to control I guess the output from industry or the output from man. I mean, we create a lot of I guess carbon dioxide ourselves as we breathe, so that has to be some influence.

Let me see if I can get some kind of resolve from you all as to how you might resolve this. Would you all be in favor of saying that we would put a moratorium on no new coal-fired utility generating stations? Would you all agree that would be a good thing?

Dr. ROOT. As far as no new? Yes, I would agree to that, but I don't think that what we can do is tear down the ones that may already be built.

Mr. BROWN. OK. So you would be willing to just keep the status quo, but don't permit any new ones.

What would you all suggest then would be the next alternate substitute for those coal-fired plants? We are going to have three billion more people, so demand for energy is going to continue to be a situation we have to deal with.

Dr. ROOT. Sure. I think what we need to be doing is putting more money into researching how you do solar and wind. That would be quite a strong thing to do.

If we could take the subsidies off of the coal and actually put that money into research to try and figure out how we can increase the wind and the solar, I think it would make a big difference.

Mr. BROWN. Let me go back to my original question. Could I get each one of you all to respond to that coal problem that we have?

I really do feel we have to find some workable solution. I don't think we can just mass produce two percent reduction a year for 40 years or whatever that number is going to come. Just say yes or no if you would.

Mr. MCKIBBEN. I thought you wanted some ideas.

Mr. BROWN. No. First I want to know if you all are going to support doing a moratorium on any new coal plants.

Mr. MCKIBBEN. Yes.

Mr. BROWN. OK. Dr. Lawler?

Dr. LAWLER. Yes, I would support it.

Mr. BROWN. OK. Dr. Root?

Dr. ROOT. Yes.

Mr. BROWN. OK.

Ms. MEDINA. As an individual, yes, but my organization isn't involved in deciding——

Mr. BROWN. I understand. I understand.

Ms. MEDINA. As an individual, yes.

Mr. BROWN. As Members of Congress, we have to find a solution. We all know the problem, and we just have to find solutions. I am just trying to get some kind of support from you all exactly what it is you might have to come up with a workable solution to this increase.

Yes, sir?

Dr. HANEY. Well, the most honest answer, Congressman, is I don't know, and I would not be able to answer it yes or no. It would depend upon are we talking about the world? Are we talking about this country?

I mean, for me to say yes and then have the rest of the world go in a different direction, I would be wasting all of our time.

Mr. BROWN. That is Congress' problem too. We have about five percent of the population I guess of the world living in the United States. I believe that is correct about.

I mean, I know we are a big user, an industrial nation and a big user of carbon dioxide, but we have to find some kind of a worldwide solution.

Let me ask you another question. As an alternative, would you all recommend that we go to nuclear power or we go to natural gas? I know that my good friend from Maryland already suggested that we are getting a lot of our energy from sources that are not friendly to our country, and I am just trying to find a resolve on that too.

What would be your alternative? I know you mentioned the sun, solar and wind.

Mr. MCKIBBEN. By far the cheapest alternative and the one that makes the most sense is chromatic conservation. That is where the savings are cheapest.

The average western European, who enjoys a lifestyle equivalent to ours, uses half as much energy per capita, which begins to give you some sense of the possibilities for conservation. When that conservation regime begins to kick in then many of the renewable technologies now coming on line begin to make a lot more sense for closing that gap.

As for population, it is a very important point that you make, but, just to sort of let you breathe a little easier, of that three

billion people that are joining the planet in the next 50 years or so, most of them are coming in countries whose carbon dioxide emissions are now small and will remain so.

Take, for instance, Tanzania, much of Africa. There was a recent study showing that the average American used more fossil fuel between the stroke of midnight on New Year's Eve and dinner on January 2 than the average Tanzanian family would use in the course of a year.

The four percent of us produce 25 percent of the world's carbon dioxide.

Mr. BROWN. Not to interrupt you, but I don't believe we want to go to Tanzania and live in those little thatched huts and get your wives to take the water bucket down to the hole and get water. We will never go back to that in the United States.

Mr. MCKIBBEN. I think we would be better off following the European standard of carbon consumption.

Mr. BROWN. OK.

Mr. MCKIBBEN. That might be a very good target for Americans.

Mr. BROWN. I got you. OK.

Ms. BORDALLO. Thank you. Thank you very much.

The Chair now recognizes Mr. Kildee.

Mr. KILDEE. I would just like to thank the panel. You have been very, very effective not just now, but through the years.

I have always believed that all is needed for evil to prevail is that good men do nothing or not enough, and we have a responsibility. We have more than a political responsibility. We have a moral responsibility to recognize the reality.

To my mind, those who question global warming are living in an unreal world. It is there, and we actually sponsor it. We have a moral obligation. I thank you for motivating me more to make sure that evil does not prevail.

Thank you very much. Thank you, Madam Chairman.

Ms. BORDALLO. Thank you. Thank you, Mr. Kildee.

The Chair now recognizes Mr. Gilchrest.

Mr. GILCHREST. Thank you, Madam Chairman.

Just very quickly, if I can help my colleague from South Carolina, we have a bill, the Climate Stewardship Act, that has been referred to the Energy and Commerce Committee with another referral to this committee, and at some point in the future I would really appreciate a hearing on that, Madam Chairman.

It is an approach in the same way that we got lead out of gasoline. We got CFCs out of the atmosphere worldwide. To use that same concept of cap and trade by setting a goal and letting the industry deal with the marketing, the ingenuity, the technology worked, so we have a bill dealing with cap and trade for CO_2 to make it a commodity that can be traded like any stock can be traded.

We feel, talking to numerous industries in this country, including Ford Motor Company, Dupont, power companies, oil industries, that by 2050 we can through technology, innovation, letting the private market, the collective ingenuity of individuals deal with this issue, we can reduce CO_2 input we feel 70 or 80 percent by 2050.

I actually think once this thing gets going—the same way with CFCs and the whole acid rain issue was dealt this way and lead in gasoline—we could probably achieve that goal actually a lot sooner, but there are ways.

I read a book a number of years ago called Human Options by Norman Cousins, and a phrase in there that was extraordinary is knowledge is the solvent for danger. That is it. Knowledge, information. We want our kids to learn in school. We want them to be good in science. We want them to do their homework. We want them to read. Well, Congress is no different.

The question I have after my soap box again, and I apologize. I actually like this. I will have to meet all the kids in Chestertown, and I did live in Vermont, East Fairfield, for three years in the 1970s. It was a blissful, wintery period of time. It was a cold snap on the planet. It was great.

Do we have an indication of what climate change will do to salmon? Will do to coral reefs? Will do to eels? In my region or neck of the woods in the Chesapeake Bay there is a pretty good industry that catches eels. They are out there in the Sargasso Sea. They swim up all those little tributaries and inlets.

Do you have a quick snapshot of eels, coral reefs, salmon and how reforestation and restoration of wetlands can sort of buffer the increasing warming?

Dr. HANEY. I will take a short answer at that. The philosophy behind adaptation is that while we are getting it right on emissions and waiting for those solutions to kick in, wildlife and fisheries resources need our help to get through this bottleneck of the next decades to centuries.

For the example of anadromous fishes like salmon, one solution would be we know temperatures are going to go up, so let us keep the stream temperatures as cold as we can. That might mean in a real practical way extending the forest buffers along the sides so that they are never, ever opened up. They are shaded everywhere all of the time.

That is the kind of solution that again I want to stress. We have to get the emissions right. There is no question. That is not going to be enough. Fish that we use, salmon and fly fishing is a huge industry in this country and elsewhere for that matter. In order for those cold water fisheries to survive we are going to need to keep stream temperatures as cool as we can.

We can even allow wolves in some places that we didn't before because the wolves keep the elk away from the streams, and the willows and the alders come back and the temperatures go down.

Dr. ROOT. May I follow up?

Mr. GILCHREST. Yes. Thank you.

Dr. ROOT. OK. As far as the coral reefs go, up to two degrees increase from preindustrial, and again we are at about .7 right now, most of the reefs in the world will be bleaching, and if we go up three degrees then they will start to die, and by four degrees we will not have coral reefs that we know anymore.

Mr. GILCHREST. Thank you.

Dr. ROOT. Actually, that does not take into account the acidification of the oceans, which I assume you will talk about in the second panel.

Ms. BORDALLO. Thank you. Thank you, Mr. Gilchrest.

The Chair now recognizes Mr. Kennedy.

Mr. KENNEDY. Thank you.

I would love it if you all can show us and do some modeling afterwards on how this directly impacts us in myriads of ways economically.

I mean, the point I was making earlier about how we are not politically astute to this is I think a real tragedy in all of this because, for example, with the oceans we just got this oceans report back, and it calls on by every expert us doubling the oceans budget, but OMB gave us half of the budget, OK?

For us, our whole agricultural budget depends on us properly being able to determine what the weather forecasting is going to be, and the forecasting is going to be impacted by global warming and also be able to detect how the oceans' currents are going to go.

If we are able to do that, we are able to better determine what our agricultural forecasting should be and so forth. It also impacts insurance policies because it depends on how much you are going to ensure certain areas and so forth.

The point I am making is that we haven't done as good a job as we need to in terms of when you mention the migratory birds, it is a billion dollar industry for hunters, OK? We need to start bringing this home. We cannot look like we are out there in the "tree hugger" mentality. We have to bring this home to people and how it impacts them in real concrete ways in their pocketbook.

This does in really powerful economic ways that are going to impact them directly, and what I think we need to do is get these models that you are talking about and break them out and do the modeling and talk about how many species do we lose every day in the rain forests, OK?

Where do we get our pharmaceuticals? How do we find out the cures to some of these diseases that we have in the world? We get them from a lot of plant life and a lot of these species, the plant life and so forth. Do people understand this?

We need to maybe start to connect the dots so they start to see oh, my God. If we are losing all these species we might be losing the cures to certain diseases in the future that may impact my family. I mean, this is what we need to start to do I think.

Dr. Root?

Dr. ROOT. Let me answer that very quickly. It actually is in answer to your previous question too.

There has been a lot of disinformation that has been going out to all of America, and the scientists, we have been sitting here saying this is not right. Here are the facts. This is not right. Here are the facts.

The disinformation has been very well funded. We have been doing what we can, but I think now everybody is saying hey, it really is happening, and now they are listening to us more. I truly believe that that is the case.

As far as the economic models, I think we do need to do a lot more, but we have to remember when people start saying oh, this is an economic issue, there are going to be losers. That is for sure. They are the ones who are going to scream and yell.

But there are going to be winners, and those winners don't even know who they are yet because they are not coalesced behind a business. They are not together. We need to understand that.

If you look at the economics of this issue, we will be 500 percent richer than we are today by 2100 in January if we don't do anything to stop global warmer. If we do, we will be 500 percent richer in November instead of in January. That is not that much of an issue to change. That is a fairly low insurance policy, I think.

Mr. KENNEDY. In terms of showing new businesses that can be created from environmental businesses obviously, but also like when you are talking about the infestation of these predatory bugs and so forth and how they can ruin crops and so forth, people need to understand these connections so that their eyes open up to what happens when you break down the natural ecosystems that are a result of global warming.

I mean, this is what we need to be doing so people get a better understanding of this, I think.

Ms. MEDINA. I just want to add, Congressman Kennedy, that I agree with all that you have both said, and I think there are some simple indicators out there that are making the public more aware.

I for one paid more than $3 for a gallon of gas today at the pump, and that is a simple economic indicator of the problem that we are facing right now and the consequences of our actions in the past.

I also want to say that we at IFAW are very concerned with animals, and we have a wealth of membership, as does Dr. Haney's organization, of people who care about animals. Putting the face of these charismatic animals on this problem and this crisis does help I think to make people more aware of the fact that what they do and the choices they make every day have dramatic and very devastating impacts on our environment.

So I am all for more complicated analyses, more study. I think I said in my testimony I think study and more facts will also help to shape the public's opinion. We don't know a lot right now. There is more that we don't know than what we do know, but there are some simple facts that I think are starting to register with the public, and you can just start with the price of gas.

Ms. BORDALLO. Thank you very much.

Mr. KENNEDY. The price of gas is what is funding stopping this environmental movement. It is what is funding the stopping of the environmental movement. That is what is funding it, your $3 price of gas.

Ms. BORDALLO. Thank you, Mr. Kennedy.

I want to thank all the Members for their questions, and I thank the witnesses very much for their excellent testimony and informative answers.

The Chairwoman now recognizes our second panel of witnesses who will be testifying on the effect of climate change on the oceans.

The Chair would also like to recognize the gentleman from Idaho, Mr. Sali, who will take the place of the Ranking Member on the committee.

Would the second panel of witnesses please be seated? I would like at this time to introduce them. Dr. Mark Eakin, the Coordinator of the Coral Reef Watch Program in the National Oceanic

and Atmospheric Administration; Dr. Ken Caldeira from the Department of Global Ecology at the Carnegie Institute of Washington; Dr. Joanie Kleypas from the Institute for the Study of Society and Environment at the National Center for Atmospheric Research in Colorado; Mr. Gary Sharp; and Dr. John Everett of Ocean Associates, Inc.

I would now like to recognize Dr. Eakin to testify for five minutes. Again, I remind the witnesses that the timing lights on the table will indicate when your time is concluded. We would appreciate your cooperation in complying with the limits that have been set.

Be assured that your full written statement will be submitted for the hearing record.

And now Dr. Eakin?

STATEMENT OF C. MARK EAKIN, Ph.D., COORDINATOR, NOAA CORAL REEF WATCH, NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

Dr. EAKIN. Hafa adai, Madam Chairwoman. Good morning to you.

Ms. BORDALLO. Thank you.

Dr. EAKIN. Good morning, Ranking Member Sali and Members of the committee. Thank you for inviting me to discuss the effects of climate change on coral reefs, an important resource for many coastal and island communities.

As you probably know, the earth's oceans have already warmed about one degree Fahrenheit during the 20th century and are very likely to warm faster in the 21st century. This warming has already influenced many natural systems, including coral reefs, even those reefs in remote, pristine environments.

Coral reefs are valuable to island and coastal communities. Globally they provide ecosystem services valued at hundreds of billions of dollars each year, so damage to reefs can be very costly. By 2050, the declining Caribbean coral reefs could reduce benefits from fisheries, tourism, shoreline protection by $350 to $870 million a year.

While healthy coral reefs significantly reduced the wave damage in parts of Sri Lanka during the 2004 tsunami, other communities where reefs have been mined for building materials suffered much greater damage and loss of life.

Of course, these valuable resources are threatened by human stress, including rising temperatures. Coral bleaching occurs when high temperatures cause corals to expel the algae that live in their tissues. When stress is prolonged or intense, corals die.

In the last 25 years since the first report of large-scale bleaching, ocean warming has accelerated the bleaching, and bleaching events have become more frequently and severe. This includes 1998 when 16 percent of the world's reefs bleached and died.

[Slide.]

Dr. EAKIN. NOAA monitors sea surface temperatures that cause coral bleaching. As an example, a map of our satellite data for the Caribbean seen on the screen shows the stress caused by high ocean temperatures.

The black regions have no stress. As the stress increases, the map changes to blue for mild stress, to green for stress that causes

bleaching, to orange, red and beyond for widespread bleaching and coral death. The graph below shows the average stress for the Caribbean during each of those years in the 21-year record.

As we go through this record, you can see the effects of rising temperatures. The stress becomes more intense and widespread, ending here with a record setting bleaching event in 2005. Unfortunately, the 2005 bleaching event that you see on the screen left 90 percent of the corals bleached and almost 50 percent dead in the Virgin Islands National Park. That is half of their corals dead, gone. Imagine losing half of the redwoods in just a few months.

The only way to eliminate the threat of coral bleaching is to reduce ocean temperatures by reducing atmospheric greenhouse gases. This lies outside the mandate of NOAA and is far beyond the reach of local reef managers. However, we can act to protect coral reefs under a changing climate.

NOAA and its international partners released a report last year entitled the *Reef Manager's Guide* to Coral Bleaching. This guide identifies three actions that managers can take to help reefs survive and recover from mass bleaching events.

First is to monitor the reefs to better understand the consequences of bleaching. Second is to reduce local stress to help corals survive during severe bleaching, and third is to develop management strategies that support reef survival, recovery and resilience in warmer oceans.

A key message of the *Reef Manager's Guide* is that multiple sources of stress act together to threaten coral reefs, and managers play an important role by taking all actions practical to control local threats to reefs.

To summarize, sea surface temperatures are rising, increasing the frequency and intensity of coral bleaching and mortality. It is very likely that this will continue through the 21st century.

Second, coral bleaching threatens resources that are important to our nation and to islands and coastal communities throughout the world. This disrupts ecosystems, ecosystem services and the people who depend upon them.

Finally, we must protect coral reefs from local stressors and manage our resources, our marine resources, with rising temperatures in mind.

Thank you, Madam Chairman. I would be pleased to answer any questions at the end.

[The prepared statement of Dr. Eakin follows:]

Statement of C. Mark Eakin, Ph.D., Coordinator, Coral Reef Watch, National Environmental Satellite, Data, And Information Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce

Introduction

Good morning Madam Chairwoman and Members of the Committee. My name is Mark Eakin, and I am the Coordinator of the Coral Reef Watch program within the National Environmental Satellite, Data, and Information Service of the National Oceanic and Atmospheric Administration (NOAA), in the Department of Commerce. This program is a component of the NOAA Coral Reef Conservation Program (CRCP), for which I also serve as the climate lead. The CRCP coordinates NOAA's many coral reef activities across its various offices. Thank you for inviting me to discuss the effects of climate change on coral reefs, an important resource to many coastal and island communities. Among NOAA's diverse missions, our tasks include understanding and predicting changes in the Earth's environment and acting as the

nation's principal steward of coastal and marine resources critical to our nation's economic, social and environmental needs.

I will focus my remarks on how climate change is impacting coral reef ecosystems and local communities. NOAA's work on climate change and marine ecosystems relevant to this hearing includes observations of the physical environment and biota, research to understand the changes in the environment and the broader ecosystem, and incorporating projected effects of climate change into NOAA's conservation and management of living marine resources and ecosystems. Climate change is one of a complex set of factors that influence marine ecosystems, including natural climate cycles, overfishing, atmospheric pollution, pesticide and fertilizer use, land use changes, inadequate storm water management, and discharge of untreated sewage. NOAA is committed to an ecosystem approach to resource management that addresses the many simultaneous pressures affecting ecosystems.

Changing climate is potentially one of the most significant long-term influences on the structure and function of marine ecosystems and must therefore be accounted for in NOAA's management and stewardship goals to ensure healthy and productive ocean environments. Changes and variations in climate may directly or indirectly affect marine ecosystems. This includes changes and variations of sea-surface temperature, ocean heat content, sea level, sea ice extent, freshwater inflow and salinity, oceanic circulation and currents, pH, and carbon inventories.

Analyses of NOAA data show that the Earth's oceans have warmed almost 1 degree Fahrenheit over the 20th century average (Figure 1). These data, along with findings from the recent Intergovernmental Panel on Climate Change (IPCC) assessments of 2001 and 2007 show that not only have the atmosphere and oceans warmed, they will continue to do so during the 21st century, at least in part due to increased greenhouse gases in the atmosphere. The 2007 IPCC Working Group II report stated: "Observational evidence from all continents and most oceans shows that many natural systems are being affected by regional climate changes, particularly temperature increases."

NOAA's Roles in Climate and Ecosystem Sciences

Within the climate science community, NOAA is a recognized leader both nationally and internationally. Our scientists actively participate in many important national and international climate working groups and assessment activities. One of NOAA's mission goals is to understand climate variability and change to enhance society's ability to plan and respond. NOAA is the only federal agency that provides operational climate forecasts and information services (nationally and internationally). NOAA is the leader in implementing the Global Ocean Observing System (NOAA contributes 51 percent of the world-wide observations to GOOS, not including satellite observations). NOAA also provides scientific leadership for the IPCC Working Group I and the interagency Climate Change Science Program. To better serve the nation, NOAA created a Climate Program Office to provide enhanced services and information for better management of climate sensitive sectors, such as energy, agriculture, water, and living marine resources, through observations, analyses and predictions, and sustained user interaction. Services include assessments and predictions of climate change and variability on timescales ranging from weeks to decades.

Within the ecosystem community, NOAA's ecosystem researchers have been at the forefront of establishing links between ocean variability and impacts on marine ecosystems. NOAA has funded some research programs specifically dedicated to evaluating impacts of changes in the physical environment on marine resources, as well as many observing programs established to aid in the management of fisheries, protected species, marine sanctuaries, corals and other specific agency mandates.

These data, primarily collected in support of NOAA's ecosystem stewardship authorities, provide a wealth of information for interpreting climate impacts when combined with NOAA's climate, oceanographic and weather information. Results of these analyses have been widely disseminated and NOAA's contributions to the emerging science of ecosystem impacts of climate change have been significant. However, a greater understanding of the full range of climate induced effects on ecosystems will require us to increase our observation of ecosystems in relation to variable climate forcing and focus our research on the mechanisms through which ecosystems are affected. In this way we can develop quantitative assessments and projections of climate's ecological impacts, including impacts on the resources on which human communities rely.

Current and Projected Impacts of Climate Change on Coral Reef Ecosystems

Coral reef ecosystems are among the most diverse and biologically complex ecosystems on Earth and provide resources and services worth billions of dollars each year to the United States economy and economies worldwide. Coral reefs have been estimated to house several million different species. They house more than one third of all described marine species—more species per unit area than any other marine environment—including about 4,000 known species of fish and 800 species of hard coral. Approximately half of all federally-managed fish species depend on coral reefs and related habitats for a portion of their life cycles. NOAA's National Marine Fisheries Service estimates the annual commercial value of U.S. fisheries from coral reefs is over $100 million per year. Local economies also receive billions of dollars from visitors to reefs through diving tours, recreational fishing trips, hotels, restaurants, and other businesses based near reef ecosystems. In the Florida Keys, for example, coral reefs attract more than $1.2 billion annually from tourism. In addition, coral reef structures buffer shorelines against waves, storms and floods, helping to prevent loss of life, property damage and erosion.

Coral reefs are under stress from many different sources, including increased sea-surface temperatures, pollution, overfishing, destructive fishing practices, coastal uses, invasive species, and extreme events (e.g. hurricanes and coastal flooding). Climate change, in particular, increases in global air and ocean temperatures, threatens coral reef ecosystems through increased occurrence and severity of coral bleaching and disease events, sea level rise, and storm activity. Increased absorption of atmospheric carbon dioxide into the oceans also leads to ocean acidification that may reduce calcification rates in reef-building organisms, as declining seawater pH reduces the availability of carbonate ions. Reduction in calcification rates directly affects the growth of individual corals and the reef's ability to maintain itself against forces that cause reef erosion, potentially compounding the "drowning" of reefs caused by sea level rise.

Ocean Acidification

The oceans are the largest natural long-term reservoir for carbon dioxide, absorbing approximately one-third of the carbon dioxide added to the atmosphere by human activities each year. Over the past 200 years the oceans have absorbed 525 billion tons of carbon dioxide from the atmosphere, or nearly half of the fossil fuel carbon emissions over this period. Because the rate of emissions has increased faster than oceanic uptake and mixing, the percentage of anthropogenic CO_2 in the oceans requires time to catch up with atmospheric increases and terrestrial uptake. Ultimately, oceanic and geologic processes acting over very long time-scales will redistribute much of the anthropogenic CO_2 into the deeper ocean waters. Over tens of millennia, the global oceans are expected to absorb approximately 90 percent of the carbon dioxide emitted to the atmosphere (Archer et al., 1998; Kleypas et al., 2006).

For over 20 years, NOAA has participated in decadal surveys of the world oceans, documenting the ocean's response to increasing amounts of carbon dioxide being emitted to the atmosphere by human activities. These surveys confirm that oceans are absorbing increasing amounts of carbon dioxide. Estimates of future atmospheric carbon dioxide concentrations, based on the IPCC emission scenarios and general circulation models, indicate that by the middle of this century atmospheric carbon dioxide levels could reach more than 500 parts per million (ppm), and near the end of the century they could be over 800 ppm. This increase in atmospheric CO_2 to 800 ppm would result in a surface water pH decrease of approximately 0.4 pH units as the ocean becomes more acidic, and the carbonate ion concentration would decrease almost 50 percent by the end of the century. To put this in historical perspective, this surface ocean pH decrease would result in a pH that is lower than it has been for more than 20 million years (Feely et al., 2004).

Recent studies indicate that such changes in water chemistry would have effects on marine life, such as corals and plankton (Orr et al., 2005). The carbonate chemistry of seawater has a direct impact on the dissolution rates of calcifying organisms (coral reefs and marine plankton). As the pH of the oceans decreases and becomes more acidic, some species of marine algae and plankton will have a reduced ability to produce protective calcium carbonate shells. This makes it more difficult for organisms that utilize calcium carbonate in their skeletons (e.g. corals, Langdon et al., 2000) or shells to build and maintain their structures. Decreased calcification may also compromise the fitness or success of these organisms and could shift the competitive advantage towards organisms not dependent on calcium carbonate. Carbonate structures are likely to be weaker and more susceptible to dissolution and erosion. In fact, a recent study showed that the projected increase in acidity

is sufficient to dissolve the calcium carbonate skeletons of some coral species (Fine and Tchernov, 2007, using CO_2 projection from Caldeira & Wickett, 2003). Ongoing NOAA research is showing that decreasing pH may also have deleterious effects on commercially important fish and shellfish larvae.

Coral Bleaching Events

As global temperatures have risen over the past 30 years, there has been a corresponding increase in the frequency of extremely high sea-surface temperatures and coral bleaching events in many tropical regions (Brown, 1997; Hoegh-Guldberg, 1999). Coral bleaching is a response of corals to unusual levels of stress primarily thought to be associated with high light and unusually high sea-surface temperatures. Bleaching occurs when a coral expels the symbiotic algae that live in its tissues and give the coral its coloration. Loss of the symbiotic algae leaves the coral tissue pale to clear and, in extreme cases, causes a bleached appearance. Corals often recover from mild bleaching. However, if the stress is prolonged and/or intense, the corals may weaken, causing them to be more susceptible to disease and other stressors, or die from direct thermal stress.

Coral bleaching has occurred in both small, localized events and at larger scales. Although many stressors can cause bleaching, large-scale, mass bleaching events have exclusively been linked to unusually high sea-surface temperatures (Glynn & D'Croz 1990; Brown, 1997; Hoegh-Guldberg, 1999). There is still much that we do not know about the effects of bleaching-associated mass coral mortality on the functioning of coral reef ecosystems and associated ecosystem services, such as fisheries, coastal protection, recreation, and tourism industries.

Through satellite and in situ monitoring of sea-surface temperatures, NOAA tracks the sea-surface temperature conditions that could lead to coral bleaching. NOAA provides access to all of its data and products, including sea-surface temperature anomalies, bleaching HotSpot anomalies, Degree Heating Weeks, and Tropical Ocean Coral Bleaching Indices. This work builds on, and complements, NOAA's efforts to monitor temperatures on coral reefs in both the Atlantic and Pacific Oceans, using instruments deployed throughout U.S. coral reefs. These systems are designed to provide local managers and scientists with the information they need to make informed decisions. When the data show that conditions are conducive to bleaching, NOAA provides watches, warnings, and alerts via e-mail to users throughout the globe through NOAA's Coral Reef Watch program and Integrated Coral Observing Network. Coral bleaching alerts allow managers and scientists to deploy monitoring efforts that can document the severity and impacts of the bleaching to improve our understanding of the causes and consequences of coral bleaching. The alerts also allow managers to take actions to reduce local stress, such as water quality and recreational abuse, that further threaten corals already under stress from bleaching.

Large scale or mass bleaching events were first documented in the eastern Pacific in the early 1980's in association with warming during the El Niño Southern Oscillation (Glynn, 1984). In 1997-98, coral bleaching became a global problem when a strong El Niño (period of warmer than average water temperature in the central tropical Pacific), followed by a La Niña (which warmed some western Pacific regions) caused unprecedented coral bleaching and mortality worldwide (Wilkinson, 2000; Wilkinson, 2002). In 1998, reefs in parts of the southern Indian Ocean and East Asia lost more than 80 percent of their corals. Parts of Palau lost up to 50 percent of their hard corals and 75 percent of their soft corals.

Coral bleaching events are not only tied to the El Niño/La Niña phenomena. In 2005, a year lacking El Niño or La Niña climate patterns, record high sea-surface temperatures were recorded in the tropical North Atlantic, Caribbean, and Gulf of Mexico. NOAA climate records show that in 2005, the eastern Caribbean experienced the warmest September water temperatures in over 100 years (Figure 2; Smith and Reynolds, 2004). Satellite records showed that the thermal stress experienced by corals in the Caribbean region 2005 was the largest and most intense event on record (Figure 3), with an average stress for the Caribbean region almost twice any level previously observed (Figure 4; Eakin et al., in prep.). NOAA's ability to assess the extent and severity of this event was the result of investments in the development and operational implementation of satellite remote-sensing products. NOAA's ability to provide synoptic views of the global oceans in near-real-time and the ability to monitor reef areas have become a key tool for coral reef managers and scientists.

While the thermal stress in the Caribbean has increased over the last 20 years, 2005 was unusually high. As a result of NOAA satellite and in situ monitoring, NOAA alerted managers and scientists to this event as it developed. The unusually high sea-surface temperatures gave rise to the most intense coral bleaching event ever observed in the Caribbean. In 2005, many reefs, including those in the U.S.

Virgin Islands, suffered bleaching of over 90 percent of their corals. In situ monitoring of reefs at the Virgin Islands National Park (NPS and USGS data) indicated a loss of 50 percent of the corals due to bleaching and disease outbreaks related to the prolonged high temperatures.

To respond to and assess the massive coral bleaching event in the Caribbean region in 2005, an interagency effort led by NOAA and the Department of Interior (DOI) was convened under the U.S. Coral Reef Task Force. This effort engaged many government and non-government partners from across the region, including local partners in Florida, Puerto Rico, the U.S. Virgin Islands, and Caribbean island nations, to assess the impacts of the 2005 mass bleaching event and make recommendations on how to prepare for and address future events. NOAA, DOI's National Park Service (NPS) and U.S. Geological Survey (USGS), and the National Aeronautics and Space Administration (NASA) employed detailed monitoring and new instrumentation to investigate the response of reefs and individual colonies to this record-breaking coral bleaching event. NPS and USGS research has been especially vital in identifying the effects that the unusually warm waters have on both bleaching and disease outbreaks (Miller et al, 2006). Some of this research will hopefully answer the question of why some corals survived while others perished. NOAA, NPS, and USGS, along with many partner agencies are analyzing the effect of this bleaching event on already vulnerable elkhorn and staghorn coral species. These two species were listed as "threatened" under the Endangered Species Act in May of 2006. It is clear that mass bleaching is a serious concern to the communities that depend upon these resources.

Even if greenhouse gases are kept at year 2000 levels, the 2007 IPCC Working Group I report concluded that global temperatures are expected to warm at almost 0.2 degrees Fahrenheit per decade. Based on current emissions, the anticipated increase in ocean temperatures over the coming decades is expected to increase the incidence of coral bleaching events (Donner et al., 2005). The 2007 IPCC Working Group II report concluded: "Corals are vulnerable to thermal stress and have low adaptive capacity. Increases in sea surface temperature of about 1 to 3°C are projected to result in more frequent coral bleaching events and widespread mortality, unless there is thermal adaptation or acclimatization by corals." This means that marine resource management needs to plan for frequent and severe coral bleaching events in the future (Marshall and Schuttenberg, 2006).

The Value of Coral Reefs to Island and Coastal Communities

In its recent report In the Front Line: Shoreline Protection and Other Ecosystem Services from Mangroves and Coral Reefs, the United Nations Environment Programme (UNEP) estimated the value of coral reefs to be between $100,000-600,000 per square kilometer. This makes coral reefs among the most valuable resources of island and coastal communities. As part of their evaluation, they considered the loss to local economies if the ecosystem services of coral reefs were lost. UNEP predicted that "over a 20-year period, blast fishing, overfishing and sedimentation in Indonesia and the Philippines could lead to a net economic loss of $2.6 billion and $2.5 billion respectively." Further, in an extensive economic evaluation, the World Resources Institute estimated that coral reef degradation continuing through 2050 could reduce benefits from fisheries, dive tourism and shore protection by a predicted total of $350 million to $870 million in the Caribbean (Burke and Maidens, 2004).

Coral reef ecosystems also provide non-economic value to island and coastal communities, which are harder to quantify. Field teams evaluating the 2004 Indian Ocean tsunami suggested that the presence of healthy coral reefs significantly reduced wave damage to some communities in Sri Lanka (Fernando and McCulley, 2005). Modeling at NOAA's Geophysical Fluid Dynamics Laboratory and Princeton University also suggests that healthy reefs can provide protection and reduce damage from tsunamis (Kunkel et al., 2006).

Unfortunately, the value of ecosystem services provided by coral reefs has been poorly quantified for many locations. Accordingly, the cost of climate change effects to coastal communities is poorly known. NOAA's Coral Reef Conservation Program intends to begin research to quantify the effects that climate change may have on socioeconomic systems in the Florida Keys, similar to a study conducted for Australia's Great Barrier Reef (Hoegh-Guldberg, and Hoegh-Guldberg, 2004). Even without strict monetary valuations, island and coastal communities have recognized the tremendous economic and cultural values that reefs provide. Because coral reefs are such valuable resources, during the 16th U.S. Coral Reef Task Force Meeting in November 2006, Governor Togiola Tulafono of American Samoa gave a statement in which he recognized the threat and implored the U.S. Coral Reef Task Force to address climate change and its impacts on coral reefs to a greater extent than it

has in the past. In his statement, Governor Tulafono said: "As a small island our way of life, a primary source of our food and a growing percentage of our economy depends heavily on a healthy coral reef. Under the present circumstances I can implement all the best management practices and still a single climate change event could devastate the majority of coral in the Territory...As the available data and scientific consensus become more persuasive and compelling on the present trends and projected impacts of global climate change, especially to the small islands dependent upon coral reefs and related resources, a set of proactive and responsive policies need to be developed along with realistic implementation strategies." This request was further echoed by delegations from other Pacific Island territories and the Freely Associated States at the 17th U.S. Coral Reef Task Force meeting in March 2007.

What Can Be Done?

As a steward of marine resources for the benefit of the nation, NOAA is working to improve its products to alert users of bleaching events through satellite and in situ observations, forecasts, and warning systems. NOAA is also working with local and regional managers to quantify the effect that increasing ocean temperatures have on coral reefs and ecosystem services, and to determine ways in which local managers can mitigate the impact of climate change on coral reefs.

The only practical way that we know of to eliminate the threat of coral bleaching is to stop or reverse the rise in ocean temperatures that has occurred over the last century. Such a reversal will very likely require reductions in greenhouse gas emissions, however, the policies to accomplish such a reduction fall outside the mandate of NOAA and beyond the reach of local managers in coastal and island communities. Recent work indicates that corals in the 21st century will have to adapt to temperature increases of at least 0.4 degrees Fahrenheit per decade to survive the increasing frequency and intensity of bleaching that we have seen. Unfortunately, ongoing studies have not found that corals have an ability to make physiological or evolutionary changes at that rate. Small latitudinal expansion of coral distributions is possible and may be occurring in one case (Precht & Aronson 2006). However, corals in higher latitudes are likely to encounter lower pH waters where skeletal growth may be depressed (Guinotte et al., 2003). This leads us to the question of what local managers can do to protect valuable coral reef resources in light of rising ocean temperatures and ocean acidification.

Indeed, what can be done for coral reefs in response to a changing climate? The U.S. Coral Reef Task Force posed this question when climate change was identified as one of the seven threats to reefs in The National Plan to Conserve Coral Reefs. As world leaders in coral reef management, NOAA and Australia's Great Barrier Reef Marine Park Authority, the Environmental Protection Agency, and the IUCN (The World Conservation Union), convened an expert workshop in 2003 to address what can be done. In 2006, we released *A Reef Manager's Guide* to Coral Bleaching.

The *Reef Manager's Guide* includes contributions from over 50 experts in coral bleaching and coral reef management from 30 organizations. The guide identifies three key actions reef managers can take to help reefs survive and recover from mass bleaching events:

(1) Increase observations of reef condition before, during and after bleaching to increase information and understanding of impacts and areas that may be especially resistant to bleaching.
(2) Reduce stressors (e.g., pollution, human use) on reefs during severe bleaching events to help corals survive the event.
(3) Design and implement reef management strategies to support reef recovery and resilience, including reducing land-based pollution and protecting coral areas that may resist bleaching and serve as sources of coral larvae for "reseeding" reefs.

The *Reef Manager's Guide* provides information on the causes and consequences of coral bleaching, and management strategies to help local and regional reef managers reduce this threat to coral reef ecosystems.

The *Reef Manager's Guide* reviews management actions that can help restore and maintain coral reef ecosystems. This review draws on a growing body of research on ways to support the ability of coral reef ecosystems to survive and recover from bleaching events. It also includes specific guidance and case studies on how to prepare bleaching response plans, assess impacts from bleaching, engage the public, manage activities that may affect reefs during bleaching events, identify resilient reef areas, and incorporate information regarding reef resilience into marine protected area design.

A key message from NOAA and its partners in the *Reef Manager's Guide* is the important role that resource managers play by taking all practical actions to control local threats to reefs. The 2007 IPCC Working Group II report addressed this issue

stating that "Non-climate stresses can increase vulnerability to climate change by reducing resilience and can also reduce adaptive capacity because of resource deployment to competing needs." There are multiple sources of stress to coral reefs and reducing other stresses can help corals survive the stress of bleaching. Research has shown that improved local management, which reduces key threats such as overfishing, provides reefs with the greatest chance of surviving and recovering from climate change (Wooldridge et al., 2005; Hughes et al., 2007). In its recently released Coral Reef Ecosystem Research Plan, NOAA describes the need to further (1) improve our understanding of the relationships between the severity of bleaching events and mortality, including what makes coral reefs resilient; (2) assess the extent and impact of bleaching on coral reefs during bleaching events; and (3) developing models to predict the long-term impacts to coral reef ecosystems from climate change. The plan can be viewed at http://coris.noaa.gov/activities/coral__research__plan/.

Conclusion

To summarize, sea-surface temperatures have risen, increasing the frequency and intensity of coral bleaching, disease, and mortality. As humans continue to add CO_2 to the atmosphere, it is very likely that this will bring further increases in sea-surface temperatures and bleaching. Increased atmospheric CO_2 threatens coral reefs that are important resources to our nation and to island and coastal communities throughout the world, doing harm to ecosystems, ecosystem services, and the people that depend on them. To protect coral reefs against rising temperatures and ocean acidification, we must take all practical actions to protect coral reefs from local stressors and manage marine resources, including planning marine protected areas, with rising temperatures in mind. NOAA looks forward to working with this Committee to ensure we have the tools and resources available to conserve, manage, and protect our coral reefs.

Madam Chairman, I thank you for inviting me to help inform the Committee on this topic. I would be pleased to answer any questions.

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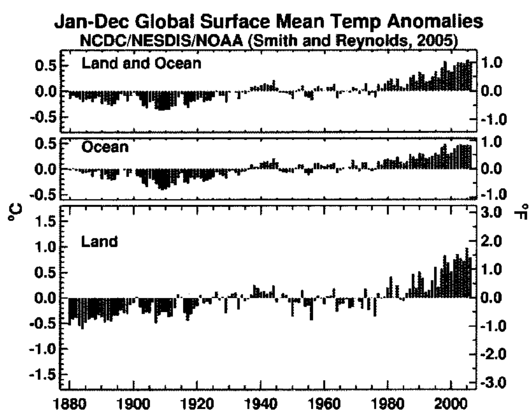

Figure 1: NOAA National Climatic Data Center data show us that the Earth's oceans have warmed almost 1 degree Fahrenheit over the 20th century average. Source: NCDC 2007. The Climate of 2006. Handout from the AMS meeting in San Antonio, TX: January 2007, http://www.ncdc.noaa.gov/oa/climate/research/2006/ann/ann06.html

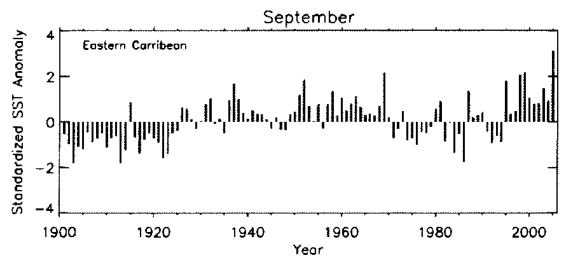

Figure 2: NOAA Extended Record of Sea Surface Temperature data showed that average ocean temperatures during June for the Western Caribbean and for September for the Eastern Caribbean exceeded temperatures seen at any time during the past 100 years. Source: Smith T. M., Reynolds R. W., 2004, *Improved extended reconstruction of SST* (1854-1997). Journal of Climate 17: 2466-2477, and data from NOAA's Earth System Research Laboratory, http://cdc.noaa.gov.

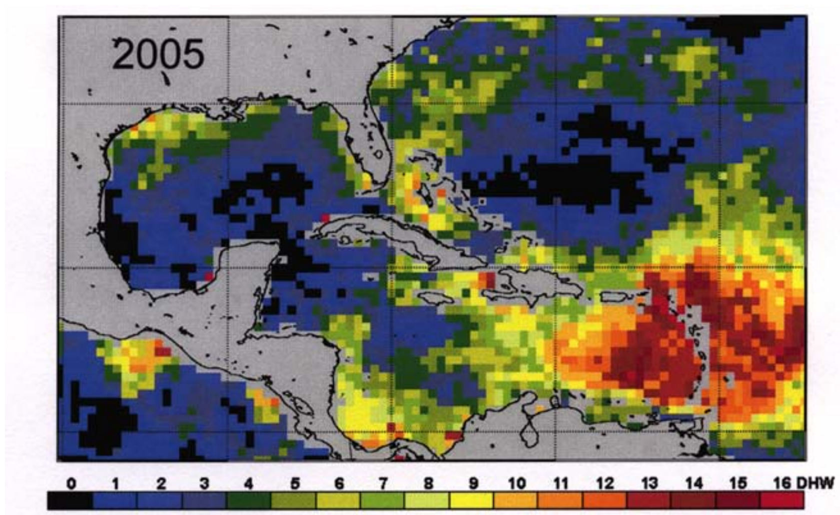

Figure 3: Map of 2005 maximum thermal stress (NOAA Coral Reef Watch Degree Heating Week values, or DHW) showing the maximum thermal stress across the Caribbean during 2005. Source: Eakin, C. M. et al., 2007, Caribbean Corals in Hot Water: Record-Setting Thermal Stress, Coral Bleaching and Mortality in 2005, intended for Nature, in preparation.

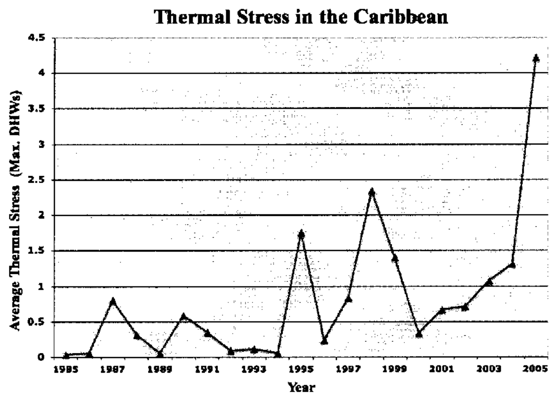

Figure 4. Graph of annual maximum thermal stress (NOAA Coral Reef Watch Degree Heating Week values, or DHW) in the Caribbean region during 1985-2005. Significant coral bleaching was reported in the Caribbean in years when thermal stress rose above 0.5, and was especially widespread in 1995, during the 1997-98 El Niño and 2005. Source: Eakin, C. M. et al., 2007, *Caribbean Corals in Hot Water: Record-Setting Thermal Stress, Coral Bleaching and Mortality in 2005*, intended for Nature, in preparation.

Ms. BORDALLO. Thank you. Thank you, Dr. Eakin.

Dr. Caldeira, you are recognized to testify for five minutes.

STATEMENT OF DR. KEN CALDEIRA, Ph.D., DEPARTMENT OF GLOBAL ECOLOGY, CARNEGIE INSTITUTION OF WASHINGTON

Dr. CALDEIRA. Hi. I am pleased and very thankful that you invited me to testify on the topic of how climate change and acidification are affecting our oceans.

I work at the Carnegie Institution and am also a professor at Stanford University where I study climate change and ocean chemistry. I worked for 12 years at a Department of Energy laboratory where I studied effects of carbon dioxide emissions in the marine environment. These effects are disturbing.

[Slide.]

Dr. CALDEIRA. We have all heard about climate change, but we might not be aware of how carbon dioxide is affecting the world's oceans. There is evidence for at least four major kinds of effects—rising sea level, heating of the ocean, decreasing ocean productivity and, of greatest concern to me, ocean acidification.

Sea level is rising. Increasingly, this is harming our coastal ecosystems and coastal and island communities. Threatened ecosystems include wetlands, corals and mangroves. These ecosystems can provide many important services, including acting as hatcheries for fisheries, protecting coasts against storm damage and in many cases helping to support tourism.

The ocean is heating up. This is affecting many ecosystems with many species shifting their ranges. It is throwing off the timing and distribution of different species that rely on each other for food. For example, breeding seabirds may not be able to find food because their food no longer lives where they normally feed.

Ocean heating is threatening coral ecosystems with extinction. With no change in how we produce energy, it is just a matter of time before other ecosystems are threatened as well.

Climate change is making much of our oceans less productive. Most life in the ocean lives near the surface where there is both food to eat and life to support growth. Life in the oceans is fed by nutrients like fertilizers coming up from the deeper, nutrient-rich waters below.

The climate change is heating the upper ocean, making it warmer. This warm water floats on top of cold water. This warm water caps the colder water below, reducing the amount of deep ocean fertilizer supplied to the ecosystems of the upper ocean.

The result is likely to be a less productive ocean in many areas with lower fish yields. There is evidence from satellite data that this reduction in productivity is already occurring in the tropics and mid latitudes.

Of all the things I have mentioned so far, the one that concerns me the most is ocean acidification. When we burn coal, oil or gas, we release carbon dioxide into the atmosphere. Eventually nearly all of this carbon dioxide will go into the ocean. The oceans are already absorbing one-third of the CO_2 we emit. That is 40 pounds of carbon dioxide going into the ocean for each American each day.

The problem is that when this carbon dioxide reacts with seawater it becomes carbonic acid, acidifying our oceans. In high enough concentrations, carbonic acid can corrode the shells and skeletons of many marine organisms.

Coral systems are perhaps the best study and may be the first to be threatened by ocean acidification. My colleague, Dr. Kleypas, will speak more to this.

We heard about this three percent CO_2. This is going away from here, but we breathe in and out, and if each time we breathe in we breathe in three percent more than we breathe out, very soon we will be in big trouble.

The important thing is how fast are volcanos and other geologic sources adding CO_2 to our atmosphere and oceans, and our current emissions exceed this natural supply of CO_2 to the oceans and atmosphere by a factor of 50. In other words, if we cut 98 percent of our emissions, we would be doubling this natural geologic source of CO_2 to our atmosphere.

If current trends in carbon dioxide emissions continue, within decades we will produce chemical conditions in the ocean that have not been seen for at least 50 million years and probably not since the time when dinosaurs became extinct. At that time, organisms like corals that made shells and skeletons out of calcium carbonate disappeared from the fossil record. It took hundreds of thousands to millions of years for life in the oceans to fully recover.

The carbon dioxide that we are using to light the lightbulbs in this room will be acidifying the oceans all over the world within a year. This is bad news for the oceans.

The good news is that we can develop energy systems that do not emit carbon dioxide into the atmosphere, and as soon as we stop emitting carbon dioxide the chemistry of the surface ocean will start improving. It is important that we act now.

Thank you again for inviting me to testify, and I look forward to answering any further questions you might have.

[The prepared statement of Dr. Caldeira follows:]

Statement of Ken Caldeira, Carnegie Institution of Washington, Department of Global Ecology, and Stanford University Department of Geological and Environmental Sciences, Stanford, California

INTRODUCTION

Climate change and acidification are both affecting our oceans. These are two different phenomena but both are primarily caused by carbon dioxide emissions to the atmosphere associated with the burning of coal, oil, and gas.

Carbon dioxide and other greenhouse gases cause the atmosphere to trap heat that would otherwise escape to space. The result in the atmosphere is changes in temperature, winds, precipitation, and evaporation. These changes in the atmosphere affect the oceans, causing changes in sea-level and ocean circulation, ultimately impacting coastal communities, fisheries, and natural ecosystems.

Nearly all of the carbon dioxide we emit to the atmosphere is ultimately absorbed by the oceans. Today, each American emits about 120 pounds of carbon dioxide into the atmosphere each day, and already about 1/3 of this is being absorbed by the ocean. Unfortunately, when carbon dioxide reacts with seawater it becomes carbonic acid. Carbonic acid, in high enough concentrations, is corrosive to the shells and skeletons of many marine organisms. Over the next decades, continued carbon dioxide emissions have the potential to create chemical conditions in the ocean that have not occurred since the dinosaurs became extinct. Such chemical conditions could cause the extinction of corals and threaten other marine ecosystems.

The solution of these problems lies in developing and deploying energy technologies that allow for economic growth and development without emitting greenhouse gases to the atmosphere. However, there are at least three other areas in which action is warranted:

(1) Climate change and acidification both act as additional stresses on marine ecosystems. Other stresses include over-fishing, coastal pollution, and introduced species. Efforts to reduce other stresses on marine ecosystems can help make marine ecosystems more resilient to the stresses posed by climate change and ocean acidification.

(2) Sea-level rise will be flooding coastal ecosystems and wetlands. These areas often act as hatcheries for commercially important fish. With sea-level rise, in the absence of coastal development, these coastal ecosystems would tend to shift towards what are now inland areas. However, if these areas are carelessly developed, such adaptive migration of these valuable ecosystems will be impossible. Management of our coastal environment and its development should take into account both future sea level rise and the welfare of coastal ecosystems, beaches, and wetlands.

(3) While the physics of climate change is reasonably well understood and the chemistry of ocean acidification is very well understood, we are just beginning to learn about the consequences of climate change and ocean acidification for marine ecosystems. Especially in the case of ocean acidification, a focused research effort could help us to understand the magnitude of the threat to marine ecosystems generally and economically important resources specifically.

CLIMATE CHANGE

By this time, the fact that greenhouse gases such as carbon dioxide cause climate change is well established. The basic physics of the greenhouse effect has now been understood for over 150 years. There are still uncertainties in the exact amount of warming that might result from an increase in greenhouse gases and even greater uncertainty in regional predictions of temperature and precipitation changes. Nevertheless, the sign of the change is clear: The Earth is getting hotter.

As the Earth heats, winds will change and areas of precipitation and evaporation will shift. All of these factors will affect ocean circulation.

Sea-level Rise

The simplest prediction is sea-level rise that results from the heating of the ocean. As the seawater warms, it expands. This thermal expansion of seawater is expected to increase sea level by about one foot during this century, if current trends in greenhouse gas emissions continue. Adding to this sea-level rise from thermal expansion is the sea-level rise from the melting of ice sheets. The amount of sea-level rise from the melting of ice sheets is far less certain, and could be anywhere from nearly zero to a couple of feet this century.

A sea-level rise of one or more feet this century means that coastal zones can expect floods that are one or more feet deeper than floods previously experienced. Beach erosion will increase. Much of the damage from sea-level rise is expected to occur during extreme conditions such as storm floods, and not during normal conditions.

A two-foot rise in sea level would eliminate about 10,000 square miles of land in the United States, an area equivalent to the size of Massachusetts and Delaware (EPA, 1989).

The natural response of coastal ecosystems (and beaches) to sea level rise that has occurred at the end of the last ice age was for these ecosystems (and beaches) to move inland as land was lost to the sea. However, today, there is significant human development along the coasts. This human development can act as a barrier to the shoreward migration of coastal ecosystems. As a result, coral ecosystems, mangroves, wetlands, beaches, and other coastal environments can be threatened by sea-level rise.

Coastal ecosystems often act as hatcheries for commercially important fish stocks. Coastal systems such as coral reefs and beaches have high tourism value.

It is important that future coastal development consider the potential for future sea-level rise and the protection of coastal ecosystems.

Ocean Heating

The heating of the ocean contributes to sea-level rise, but it has other effects on the marine ecosystems. Perhaps the clearest case relates to coral reefs, where the bleaching of coral reefs has been closely related to changes in sea surface temperatures.

However, the warming of the oceans has more subtle effects on marine ecosystems. There has been extensive documentation of fish stocks moving poleward in response to warming of the North Atlantic ocean. There is no expectation that entire ecosystems are capable of migrating as a single unit. So, for example, fish species may migrate northward, but seabirds that feed on those fish have no way of knowing that the fish have migrated. Thus, the seabirds may seek food unsuccessfully in their traditional feeding grounds. Recent seabird deaths in northern California and Oregon have been associated with shifts in winds and resulting changes in ocean circulation and availability of food (Barth et al., 2007).

Clearly, polar ecosystems cannot move further poleward to maintain the temperatures these ecosystems need. Thus, polar marine ecosystems are particularly threatened.

Oxygen dissolves more easily in cold water than in warm water. Thus, fish can suffocate in warm water. Very active fish, like tuna, have a very high oxygen demand. This is a primary reason why adult tuna prefer to live in cold water environments where oxygen is plentiful. Warming of the ocean can be expected to increase the oxygen stress on marine ecosystems (Pörtner and Knust, 2007).

Stratification and Marine Productivity

Most life in the ocean lives near the surface where there is both light and food. The base of the food chain are typically tiny photosynthetic organisms that rely on nutrients (essentially fertilizer) mixed up from below.

Warm water floats on top of cold water. As the surface ocean heats, the contrast in temperature between the surface water and deeper water increases. This inhibits mixing between the surface ocean and deeper ocean waters.

Deeper ocean waters are enriched in nutrients. When mixing of this nutrient-rich water up to the surface is inhibited, less nutrients are supplied to the productive surface layers of the ocean. With a diminished nutrient supply, there will be less growth of the plants and algae that form the base of the food chain (Behrenfeld et al., 2006), and marine ecosystems can be expected to become less productive, impacting fisheries.

A relationship between increased sea-surface temperature and decreased biological productivity in the ocean has been confirmed for the tropics and mid-latitudes based on satellite observations of sea surface temperature and chlorophyll concentrations.

OCEAN ACIDIFICATION

Today, nearly 30 billion tons of carbon dioxide are released to the atmosphere from the burning of fossil fuels (and from secondary sources such as cement manufacture). About 10 billion tons of carbon dioxide are going into the ocean each year. The average American emit about five times as much carbon dioxide as the average person on this planet—the average American emits about 120 pounds of CO_2 each day, with about 40 pounds of this CO_2 going into the oceans each day for each

American. It is unreasonable to expect that so much CO_2 could go into the ocean without having negative consequences for marine biota.

EPA Water Quality Standards

The U.S. Environmental Protection Agency (1976) Quality Criteria for Water state: "For open ocean waters where the depth is substantially greater than the euphotic zone, the pH should not be changed more than 0.2 units outside the range of naturally occurring variation—" Atmospheric CO_2 concentrations would need to be stabilized at <500 ppm for the ocean pH decrease to remain within the 0.2 limit set forth by the U.S. Environmental Protection Agency (1976).

A Personal History

The first paper quantifying the greenhouse effect was called "On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground" (Arhenius, 1896). Back then, the tern "carbonic acid" was used to refer to carbon dioxide, because carbon dioxide forms carbonic acid when it dissolves in water.

I began studying this issue when I worked for at a Department of Energy laboratory (Lawrence Livermore National Laboratory). I was also scientific co-director of the DOE Center for Research on Ocean Carbon Sequestration. We were researching the feasibility of slowing climate change by intentionally placing carbon in the ocean.

As part of this research effort, DOE funded investigation of the effect of carbon dioxide on marine organisms, including both primary research and synthesis of work funded by other organizations. It soon became apparent that CO_2 could threaten marine organisms not only at the high concentrations that might be relevant for an intentional ocean storage project but also at the lower concentrations expected to result from the oceanic uptake of carbon dioxide from the atmosphere.

I wrote the study that introduced the term "ocean acidification" (Caldeira and Wickett, 2003). When we first submitted this study for publication in Nature magazine, we compared the oceanic effects of releasing carbon dioxide into the deep ocean with the effects of releasing carbon dioxide into the atmosphere. The editors of Nature magazine felt that the effects of releasing carbon dioxide into the atmosphere were so alarming that it was unnecessary to show the effects of deep sea injection. Thus, the study as published focused on the effects of atmospheric release. In that study, we concluded that future carbon dioxide releases could produce chemical conditions in the oceans that have not been seen in the past 300 million years, with the exception of rare brief catastrophic events in Earth history.

Ocean Acidity, Biota, and the Geologic Record

Many marine organisms, including corals and clams, make their shells or skeletons out of calcium carbonate. The upper ocean is super-saturated with respect to calcium carbonate minerals, which means there is a chemical force helping these organisms to form and maintain their shells and skeletons. These organisms use both calcium and carbonate to form calcium carbonate. The ocean acidity produced by carbonic acid (carbon dioxide) attacks carbonate, removing one of the essential building blocks needs by corals and clams and many other marine organisms to build their shells and skeletons.

It is very easy to predict the future chemistry of the upper ocean. The chemistry is very well understood. You can take a bucket of seawater and put it under a bell jar with a different atmospheric CO_2 concentration, and then measure the chemistry of the water—and the measured chemistry will agree very closely with what would be predicted by calculations. This chemistry has been well understood for decades. (This chemistry is very similar to the chemistry of blood. In fact, the science of seawater chemistry was based on approaches developed to understand blood chemistry.)

If you take a bucket of seawater from the Southern Ocean or Arctic Ocean and place it under a bell jar with CO_2 concentrations expected later this century under "business-as-usual" scenarios, you will find that this water is able to dissolve the shells of some marine organism (see Figure). If you do the same thing with seawater from the tropics, you will find that you create the kind of chemistry in which no coral is found living in the real ocean today—it would be so difficult for the corals to produce their skeletons that they would be unlikely to compete successfully with sea grasses, algae, and other organisms seeking that ecological space.

The United States has funded project to drill into the ocean floor over the past few decades. From these drill holes cores are withdrawn. From the sediments in these cores we have gained an understanding of the changes in deep ocean chemistry over the past 50 million years. It is now clear that even if atmospheric CO_2 is stabilized at 450 ppm, the deep ocean will be more corrosive to carbonate

minerals than at any time over the past 50 million years (Caldeira and Wickett, 2005; Tripati et al. 2005).

My PhD dissertation work was on what occurred to ocean chemistry when the dinosaurs became extinct some 65 million years ago. At that time, nearly every marine organism that made a shell or skeleton out of calcium carbonate disappeared from the geologic record. It took hundreds of thousands to millions of years for marine biology to recover. For example, some few coral individuals survived but it took 2 million years for them to repopulate the coasts of the tropical and subtropical oceans.

In the next decades, if CO_2 emissions are unabated, we may make the oceans more corrosive to carbonate minerals than at any time since the extinction of the dinosaurs. I personally believe that this will cause the extinction of corals, even though this cannot be proved conclusively.

Knowns, and Known and Unknown Unknowns

We know that our carbon dioxide emissions, if unabated, will produce chemical conditions in the oceans that have not been experienced for many millions of years. There is good reason to believe that this could "put the nail in the coffin" of the remaining coral reefs throughout the world. However, much is unknown.

Most experiments on the biological response of marine organisms to increased CO_2 have been conducted on relatively few organisms over relatively short periods in laboratory environments. Most of these experiments have focused on corals and other organisms with calcium carbonate shells or skeletons.

Nobody has yet looked at how ocean acidification might affect fish eggs or fish larvae. Nobody knows how ocean acidification impacts on the plankton that form the base of the food chain might affect the organisms at the top of the food chain.

AN EXAMPLE: CLIMATE CHANGE PLUS OCEAN ACIDIFICATION

It was mentioned above that seawater chemistry is very similar to blood chemistry. When we use our muscles, the CO_2 concentration in our blood increases, and our blood becomes more acidic, and this causes the hemoglobin in our blood to bind to the CO_2. When this CO_2-carrying-hemoglobin reaches our lungs, contact with the atmosphere in our lungs causes our blood to become less acidic, and this causes the hemoglobin in our blood to give up the CO_2 and bind instead to oxygen. In this way, the chemistry of our blood regulates oxygen transport and CO_2 removal.

Similar processes go on in organisms like fish and squid (Pörtner et al., 2005). But, as mentioned above, heating of the ocean will decrease the oxygen content of water. In addition, there will be much more carbon dioxide dissolved in the seawater. Thus, the ocean water will look a lot more like oxygen-depleted CO_2-rich blood in a muscle. It is expected that in this environment the hemoglobin (or its relative in other species) may not give up as much of its CO_2 or bind to as much oxygen. Thus, this can contribute to oxygen stress in marine organisms.

It is not known how important this type of effect might be, or at what atmospheric CO_2 levels this might to impact ecosystems, including economically valuable species. But this shows that climate change and ocean acidification have the potential to act synergistically to damage marine ecosystems.

OBSERVATIONS

The clearest way to reduce the risks climate change and acidification pose for our oceans is to reduce carbon dioxide emissions.

Climate change and ocean acidification will stress ocean ecosystems. Reduction of other stresses on marine systems (e.g., overfishing, loss of wetlands) will make marine systems more resilient to climate change and ocean acidification.

The physics of climate change are fairly well understood and the chemistry of ocean acidification is very well understood. While there is enough information to be concerned and alarmed, there is still great uncertainty on the response of marine ecosystems to these stresses. More research could help inform sound policy development. Research on biotic effects of ocean acidification is especially lacking.

Managements of our coastal environments, both on land and in water, should take climate change, ocean acidification, and sea-level rise into consideration.

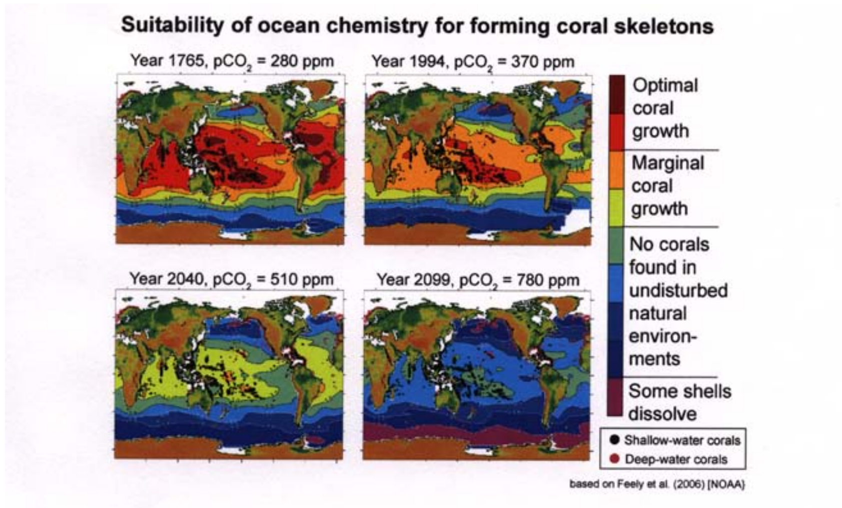

Figure 1. Maps showing the distribution of ocean chemistry suitable for coral growth for different time periods, assuming "business-as-usual" CO_2 emissions. Colors represent the chemical force promoting the development of coral skeletons. Year 1765: Several hundred years ago, before the carbon dioxide emissions of the industrial revolution, nearly all coral reefs are found in the red-colored regions with a few in the orange and regions. No corals are found in the more blue and purple colored regions. Year 1994: Already, as a result of historical carbon dioxide emissions, the area that is most suitable for coral growth has retreated to the western Pacific Ocean (and a little bit of the Indian Ocean). Most existing corals are already in marginal environments for coral growth. Year 2040: Already, there is no place left in the ocean that is optimal for coral growth. In parts of the Southern Ocean, shells of some organisms, such as pteropods, are starting to dissolve. Year 2099: By the end of the century, there is no place left in the ocean with the kind of ocean chemistry where corals are found growing naturally. Shells of marine organisms are dissolving through most of the Southern Ocean.

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Mr. KENNEDY [presiding]. Thank you very much.

Dr. Kleypas?

STATEMENT OF JOAN A. KLEYPAS, Ph.D., INSTITUTE FOR THE STUDY OF SOCIETY AND ENVIRONMENT, NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Dr. KLEYPAS. Thank you, Congressman Kennedy and other Members of the Subcommittee, for this opportunity to speak with you today. I am a scientist at the National Center for Atmospheric Research, and I study the interactions between climate and marine ecosystems.

I would like to speak about a topic that I feel is one of the most important environmental issues of our time. That issue is ocean acidification and what it means for our marine ecosystems.

[Slide.]

Dr. KLEYPAS. I want to repeat two of the main points made by Dr. Caldeira. First, every year the oceans absorb about a third of the carbon dioxide released by humans to the atmosphere. This is a natural service provided by the oceans that helps reduce the rate of climate change.

Second, this uptake is not without consequences. The additional carbon dioxide in the oceans is turning them more acidic. Although we cannot feel this change, it is predictable, measurable, and it is accelerating.

There are two main ways that increasing acidity affects marine organisms. First, it affects the basic life functions such as respiration and growth. Second, in a broad group of organisms that we call marine calcifiers it affects their ability to form their calcium carbonate shells or skeletons.

With respect to life functions, the first question that comes to mind is will marine organisms be stressed by ocean acidification? Only a few experiments have so far been conducted to answer this.

As expected, it appears that some organisms will be stressed while others will not. Squid, for example, appear to be more sensitive than fish, and early life stages of marine organisms such as larval fish appear to be more sensitive than adults.

What we know the most about is how changes in acidity affect the ability of many marine organisms to build their shells or skeletons. This includes many groups from microscopic algae at the base of the food chain to familiar groups like claims and oysters, starfish and corals.

As Ken said, corals are the best studied amongst these, and if current trends in emissions continue there is strong evidence that coral calcification rates will decline by 10 to 50 percent by the middle of this century.

What does it mean to these organisms to have reduced ability to grow shells? It is like taking away their fundamental building material. These organisms grow shells and skeletons for a variety of reasons such as protection, competing for space or anchoring to the sea floor, amongst many others. Suppressing skeletal growth is thus very likely to decrease an organism's ability to survive.

Another critical question. How will ocean acidification affect marine ecosystems and food chains? There are indications that the ranges of some species will be reduced and that food webs will be altered—this is very similar to the terrestrial information we had today—including some species that support commercially important fish species.

Researchers are beginning to take up the task to find out how such efforts will cascade through marine food webs. There has been little research on this unfortunately, but it is urgent that we figure this out.

Calcium carbonate is essential at the ecosystem level as well. Coral reefs exist simply because corals and other organisms produce this mineral faster than it is removed or dissolved. Reef structures are important. They support high biodiversity in fisheries, they protect many coastlines from storms, they provide the quiet conditions necessary for mangroves and seagrass beds, and they allow the existence of low-lying coral atolls.

If calcium carbonate production decreases the supply of coral sediment also decreases, leaving islands more vulnerable to erosion, particularly in the face of rising sea level and extreme weather events.

Based on present day observations and the geological record, ocean acidification will alter our marine ecosystems in fundamental ways. Unfortunately, the problem of ocean acidification is a relatively new discovery, and we are just beginning to understand how far reaching the effects may be. We have much work to do.

The obvious solution is to reduce carbon dioxide emissions. This will not only decrease ocean acidification; it will decrease the other compounding problems associated with climate change. In the meantime, given the problem of multiple stressors on ecosystems, it makes sense to address those stresses that we can control, like poor land use practices and overfishing, while we implement solutions to the global problem of rising atmosphere CO_2.

Personally I feel that ocean acidification is one of the greatest risks we face if we continue to allow carbon dioxide to build up in the atmosphere. The implications are important to life in the oceans as we know it and ultimately to our own lives.

Thank you very much.

[The prepared statement of Dr. Kleypas follows:]

Statement of Joan A. Kleypas, Ph.D., Scientist, Institute for the Study of Society and Environment, National Center for Atmospheric Research [1]

Introduction

I thank Chairwoman Bordallo, Ranking Member Brown, and the other Members of the Subcommittee for the opportunity to speak with you today on the future of our wildlife and oceans in a changing climate. My name is Joan Kleypas. I am a Scientist at the National Center for Atmospheric Research in Boulder, Colorado. My personal research has focused on the interactions between marine ecosystems and climate change, with particular emphasis on the impacts of climate change on coral reef ecosystems. I have authored or co-authored between 30 and 40 peer-reviewed scientific journal articles, book chapters, and technical documents, and have presented more than 30 invited talks worldwide. I have co-organized several international workshops on issues related to climate change and marine ecosystems. I currently serve on two committees related to carbon and the oceans: the Ocean Carbon and Biogeochemistry Scientific Steering Committee, and the European CarboOcean International Advisory Board. You have asked me to provide insights on issues related to the known and predicted impacts that climate change is having and is expected to have on wildlife and oceans. My testimony will focus on the emerging problem of ocean acidification. I have worked on this issue since 1998, and have led several efforts to improve our understanding of this process and what it means for ocean life.

Background

A large proportion of the carbon dioxide (CO_2) released to the atmosphere is absorbed by the ocean. A recent inventory of carbon in the oceans estimates that by mid-1990s, the oceans had already taken up nearly half of the total carbon dioxide released by human activities between 1800 and 1994. Without this process, the atmospheric concentration of carbon dioxide would have risen from 280 ppmv to be about 435 ppmv rather than the current concentration of 380 ppmv. The natural sequestration of carbon dioxide by the oceans thus slows down the build-up of greenhouse gases in the atmosphere.

However, the additional CO_2 in the water column is resulting in "ocean acidification," the progressive shift of ocean pH toward more acidic conditions. This shift is occurring because carbon dioxide combines with seawater to form carbonic acid, which lowers the pH. Once the concentration of carbon dioxide in the atmosphere reaches twice that of preindustrial times (560 ppmv), the pH of the surface ocean will have decreased from a preindustrial average of about 8.16 to about 7.91. Because pH is reported on a logarithmic scale, this small change in pH represents a rather large increase (78%) in hydrogen ion concentration, with clear implications for biological processes. These changes will also cause shifts in the relative concentrations of other dissolved carbon species in the ocean. Notably, the concentration of the carbonate ion, which is a major building block for the skeletons and shells of many marine organisms, will decrease by about 34%.

Even though the process of ocean acidification was predicted since the 1970s, only recently has this process been verified by large-scale measurements of carbon in the ocean through programs such as the World Ocean Circulation Experiment and the Joint Global Ocean Flux Survey. Based on what we know about ocean pH in the past, the seawater chemistry of the surface ocean is already altered to a state that is considerably outside the range of conditions of the past several hundred thousand years and possibly twenty million years. The surface ocean is everywhere experiencing a decline in pH ("acidification"). Today, the surface ocean remains saturated with the calcium carbonate minerals aragonite and calcite. The "saturation horizon," below which these minerals will dissolve, is becoming shallower as the oceans take up more CO_2. Within this century, it is predicted that the saturation horizon for aragonite will reach the surface near the poles, particularly in Antarctica.

In the remaining testimony, the terms "increasing CO_2" and "ocean acidification" are used interchangeably. Although these are not technically the same, the justifying assumption is that increasing atmospheric CO_2 is the absolute driver of ocean acidification.

The Effects of Ocean Acidification on Marine Organisms

The potential effects of ocean acidification on marine biota were not recognized until about a decade ago, when experiments indicated that major groups of marine organisms were affected by ocean acidification. Ocean pH is a fundamental property

[1] The National Center for Atmospheric Research (NCAR) is sponsored by the National Science Foundation.

of seawater that affects almost every aspect of biochemistry. First, it affects organisms physiologically; that is, such basic life functions such as photosynthesis, respiration, growth, etc. Second, in a broad group of organisms that we call "marine calcifiers," it affects their ability to form their calcium carbonate shells or skeletons. For each, I will outline what we know and also what we don't know. Most of the information I present here draws from two major reports on ocean acidification published by the Royal Society [1], and by a U.S. effort jointly funded by the National Science Foundation, the National Oceanic and Atmospheric Administration, and U.S. Geological Survey [2]. Currently, there is much more information regarding the calcification response of marine organisms to ocean acidification than the physiological response.

Physiological response of primary producers and microorganisms. The bulk of the primary production in the oceans is carried out by phytoplankton, unicellular algae that live suspended in the upper few hundred meters of the ocean. These are the foundation for most marine food webs. Marine algae are not as CO_2-limited as terrestrial plants, because they possess a "carbon concentration mechanism." Thus, CO_2 fertilization does not seem likely for most marine primary producers, and most experiments have confirmed this. One exception is in coccolithophorids, which showed an increase in primary production under conditions of elevated-CO_2 experiments and elevated nutrients; in similar experiments with normal nutrient levels, primary production did not increase. Some true marine plants, such as seagrasses, may be carbon-limited and may grow faster in the future, but this has not been tested. Almost no realistic experiments have been conducted on the vast array of other marine microorganisms.

Physiological response of higher marine organisms. In terms of physiological response, the first question that comes to mind is "will marine organisms be adversely affected by a lowered pH?" Most of the experiments conducted so far were designed to simulate the effects on ocean biota adjacent to deep-injection CO_2 disposal sites, and most were designed to measure acute physiological effects and mortality. Most of the organisms in these tests experienced increasing rates of mortality with decreasing pH, and some of the experiments indicated that physiological stress was apparent even near slightly elevated concentrations. These experiments did show that some species are not likely to be adversely affected. For example, some copepod and amphipod species appear to be tolerant of even extreme increases in elevated CO_2 concentrations, and/or recover following an acute exposure. These and other species that are adapted to existing extreme environments in the ocean (e.g., the unusual communities associated with hydrothermal vents) are not likely to be directly affected by ocean acidification.

Few experiments have been so far been conducted to test the physiological response of marine organisms to pH changes consistent with projected atmospheric CO_2 concentrations. These experiments have primarily been conducted on mollusks, echinoderms and fish. The basic argument about the effects of ocean acidification on higher-order organisms is that it causes acidosis of animal tissue and body fluids, which can have long-term effects on metabolic functions. A summary of these findings so far are:

1. Chronic exposure of fish to lowered pH can cause changes in metabolic states, such as including increased or decreased respiration rates, changes in blood chemistry pH, or changes in enzymatic activities.
2. Sea urchins grown in lower-pH waters show an inability to regulate internal acid-base balance, which would limit or inhibit growth. Development of sea urchin larvae is also slowed or abnormal.
3. Mollusks grown in lower-pH waters exhibit a slower metabolic rate, a decrease in haemolymph pH, and a decrease in growth rates. Squid appear to be particularly sensitive to ocean acidification because of their high metabolic rate and pH-sensitive blood oxygen transport.
4. Some coral species have survived low-pH conditions in the lab for one year, despite the complete dissolution of their skeletons.
5. In most species, larval stages are considered more sensitive to pH changes than the adults, because they have less-developed systems for regulating internal pH.

[1] Royal Society, 2005. Ocean acidification due to increasing atmospheric carbon dioxide, Policy Document 12/05. The Royal Society. http://www.royalsoc.ac.uk/document.asp?id=3249

[2] Kleypas JA, RA Feely, VJ Fabry, C Langdon, CL Sabine and LL Robbins. 2006. Impacts of Ocean Acidification on Coral Reefs and Other Marine Calcifiers. A Guide for Future Research, Report of a workshop sponsored by NSF, NOAA and the USGS. 88pp. http://www.isse.ucar.edu/florida/

Even though many of these changes are not immediately detrimental to an organism, they may affect long-term growth and reproduction and may thus be harmful at population and species levels.

Effects on marine calcifiers. So far, experiments have been conducted on at least six major groups of calcifying organisms: coccolithophores (microscopic algae); foraminifera (microscopic protozoans); coralline algae (benthic algae); echinoderms (sea urchins and starfish); mollusks (snails, clams, and squid); and corals. While the responses vary somewhat between the major groups, nearly all experiments have that calcification rates decline with decreasing pH. Corals are the best studied among these and the range of experiments indicates that calcification rates will decline by 10-50% if atmospheric CO_2 concentrations reach double the preindustrial concentrations.

The ability of marine calcifiers to adapt to these pH changes has not been adequately tested. Corals that have been grown under decreased pH conditions for a year or more do not show signs of adapting. Calcification rates in one coccolithophore species appears to be maximized at near present-day conditions, which suggests that this species can adapt to new CO_2 conditions. Geological and paleontological data show a waxing and waning of skeletal sizes and thicknesses over time, consistent with changing ocean chemistry, which indicates that many groups do not adapt to such changes.

Ocean acidification not only compromises the ability of these organisms to secrete calcium carbonate, it also increases the rate at which existing calcium carbonate dissolves. This may be particularly important for groups that already exist near the "saturation horizon" of calcium carbonate, such as cold water corals that live in deep waters above the saturation horizon, and planktonic marine snails called "pteropods" that are particularly abundant in Antarctic waters and are an important food species from many commercial species.

There is essentially no information regarding how changes in calcification rate will affect the ability of organisms to survive in nature, and most of what we know is based on assumptions that organisms grow shells and skeletons for a variety of reasons, such as: protection, gathering light for photosynthesis, competing for space, anchoring to the substrate, and reproduction. Suppressing skeletal growth is therefore likely to decrease an organism's fitness and ability to function within its ecological community. Also, the function of the calcium carbonate may change over the lifetime of an organism. For example, calcium carbonate in a larval echinoderm provides the ballast that allows the larvae to settle onto suitable substrate, but later provides its protective exoskeleton. Recent experiments show that two coral species completely lose their skeletons (through dissolution) when pH is reduced to 7.4 (which would occur if atmospheric CO_2 concentrations exceeds 1200 ppmv); yet they survived in the lab, and once returned to a normal pH, grew new skeletons. This provides a positive note that some coral species could survive ocean acidification, albeit in a much altered state. Indeed, there is evolutionary evidence that some corals may have indeed survived mass extinction events in this way, and provided the stock from which new coral species evolved (over time spans of millions of years). But the survivability of "naked corals" in the field is questionable, and their ecological role in the coral community would be altered.

The Effects of Ocean Acidification on Marine Ecosystems

Changes in the physiology and calcification rates of marine organisms will undoubtedly affect marine ecosystems and food chains. There are indications that the ranges of some species will be reduced, and that food webs will be altered, including those that support some commercially important fish species. Researchers are beginning to take up the task to find out how such affects will cascade through marine food webs, but at the moment there has been little research on this.

Calcium carbonate is also important at the ecosystem level. Coral reefs exist simply because corals and other organisms secrete calcium carbonate faster than it is removed. Reef structures are important because they 1) support high biodiversity and fisheries, 2) protect many coastlines and provide the quiet conditions necessary for mangroves and seagrass beds, and 3) allow the existence of low-lying coral atolls. The ability of coral reefs to keep up with rising sea level is well documented. This ability is because the amount of calcium carbonate produced by a reef community exceeds the amount that is removed by erosion and dissolution. If calcium carbonate production decreases, then reef-building and the constant supply of coral sediment will also decrease. Mass coral die offs in recent years has led to considerable erosion on some reefs; the Galápagos reefs, for example, were formed over a period of 3000 years, but were eroded away within a decade following the 1982-1983 coral bleaching event. Ocean acidification not only decreases calcification rates on reefs, it also increases dissolution rates, so that net reef building declines. Any reduction in

calcium carbonate increases the potential for island erosion, particularly in the face of rising sea level.

Based on present-day observations and the geological record, it seems certain that ocean acidification will alter our marine ecosystems. The rapid disappearance of marine calcifying organisms in some mass extinction events in Earth history has been attributed, at least in part, to ocean acidification. Unfortunately, the problem of ocean acidification is a relatively new discovery and we are just beginning to understand how far-reaching the effects may be. We have much work to do.

Solutions

Ocean acidification may be one of the greatest environmental risks we face if we continue to allow CO_2 to build up in the atmosphere. The obvious solution is to reduce CO_2 emissions; this will not only decrease ocean acidification, it will decrease many of the other problems associated with climate change. Although seemingly impossible now, should new technologies be developed to not only slow atmospheric CO_2 increases, but actually remove CO_2 from the atmosphere, the current acidification of the upper ocean would be reversed. It is true that much of the carbon absorbed by the oceans has been transported by ocean circulation to deeper depths, and will remain in the ocean for hundreds of years. The upper ocean, however, is in near equilibrium with the atmosphere, and removing CO_2 from either the ocean or the atmosphere causes CO_2 to diffuse across the air-sea interface (gas diffuses from the region of high concentration to low concentration). Thus, restoring the atmosphere to its preindustrial state would restore the surface ocean to its preindustrial pH.

It is tempting to recommend some limit to how acidic the ocean can get before irreparable damage will occur. The "safest" value would be the maximum values experienced during the glacial interglacial cycles (essentially the preindustrial levels). Other values that have been proposed include: the value at which surface waters would become undersaturated with the minerals that organisms need to build shells (550 ppmv)[3]; or the value at which coral reefs would begin to suffer net erosion (450-1000 ppmv)[4]. However, these are only two of the many other potential thresholds that have not been measured, such as concentrations that: 1) impact fish species or their food resources, 2) impact larval survival and recruitment of important species of fish and shellfish, and 3) cause changes in community composition in ways that affect the ability of the oceans to recycle important nutrients such as carbon, nitrogen, and phosphorus. In reality, there are likely to be a continuum of thresholds, and predicting these is complicated by the problem of "multiple stressors" on marine ecosystems, such as pollution, poor land-use practices, and overfishing.

As technologies to stabilize or reverse CO_2 concentration in the atmosphere are developed, it is not only timely but urgent that we improve our understanding of how ocean acidification will affect marine life across molecular to ecosystem scales. Given the multiple stressors in our environment, actions should be taken to minimize additional stresses to organisms or ecosystems that are particularly vulnerable to ocean acidification (for example, reducing fishing quotas for species that experience lowered reproductive success). Acquiring the information needed to advise policy makers on these issues will require coordinated research across multiple institutes and government agencies. In some cases, even basic information on the distribution patterns of major groups of marine organisms is lacking and such information would greatly inform our ability to predict future biological responses. Existing efforts by NOAA and NASA should be expanded to improve monitoring and observations; but much of the key research needed is at the cellular to ecosystem levels and requires basic academic research through both NSF and EPA.

Conclusions

Ocean acidification is occurring now and in all oceans. pH of the surface ocean, where the bulk of ocean production and biodiversity exist, is changing in lock-step with changes in atmospheric CO_2 concentration. The long-term effects of ocean acidification on species and ecosystems are consistent with recent observations that tie mass extinction events of Earth's history to ocean acidification. Evidence from multiple scientific disciplines points to the same conclusion: ocean life is sensitive to changes in ocean pH, and will be increasingly affected by ocean acidification. Many calcifying species are likely to be affected by a decreased capacity to grow and

[3] Orr, J.C., Fabry, V.J., Aumont, O., et al. (2005) Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms, Nature, 437, 681-686.

[4] Yates, K.K. and R.B. Halley (2006) CO32- concentration and pCO_2 thresholds for calcification and dissolution on the Molokai reef flat, Hawaii, Biogeosciences, 3, 357-369.

maintain their shells and skeletons. Many other species may be affected physiologically, simply by changes in their internal pH. Because ocean acidification is likely to affect such a broad array of marine organisms, we can expect to see significant changes in marine ecosystems, including those that support commercial fishing. Ocean acidification is an emerging scientific issue, but it is also one of high environmental risk. Because of that, I am deeply grateful for this opportunity to address this Subcommittee, and I look forward to answering your questions.

Response to questions submitted for the record by Dr. Joanie Kleypas

QUESTIONS FROM THE HONORABLE MADELEINE BORDALLO, CHAIRWOMAN

1. How sure are we about the chemistry of ocean acidification? Is there debate on this point?

The chemistry of ocean acidification is complicated, but it is well understood and predictable. Because carbon dioxide concentration is the main factor determining pH of the surface ocean, predictions of the degree of ocean acidification in the future are well known. There are also secondary factors that affect the concentration of carbon dioxide, such as the degree of temperature rise or changes in biological activity in the ocean. However, none of these significantly affect the ocean acidification process.

There is strong consensus among scientists that ocean acidification is occurring and will continue to occur in concert with increases in atmospheric carbon dioxide concentration; and to my knowledge, there is no debate about whether ocean acidification is happening. There is one published paper that attempted to assert that the biological impacts of ocean acidification would be small [1], but this paper failed to acknowledge a decade's worth of studies on the biological impacts of ocean acidification [2].

2. Given that reductions in carbon emissions are not going to be eliminated tomorrow, can you talk more about the steps that managers can take now to help marine ecosystems be more resilient in the fact of climate change and ocean acidification? For instance, how might they want to change their approach to the management of wetlands and coastal areas?

Climate change and ocean acidification are two very important stressors on coastal and marine ecosystems, but there are many other factors as well. During this period where we are committed to some degree of climate change, the first management approach is one that concentrates on removing stresses that can be controlled. Some of these actions are obvious, such as reducing overfishing, pollution, and land-based activities (e.g., deforestation) that negatively affect the marine environment. A healthy ecosystem is simply more resilient to climate change than one that is already stressed.

A second strategy would be to identify those regions that are least/most vulnerable to climate change and other stresses. Which regions will benefit the most from conservation, and where should we concentrate our conservation efforts? Which regions are most likely to remain viable during our committed period of climate change? What are the best factors (e.g., biodiversity, size, protection from other stressors) for determining such resilience?

Finally, because the responses of ecosystems are inherently difficult to predict, management activities need to become more adaptive in two ways. First, managers will need to adjust their management strategies to incorporate new findings and information about their particular regions. Second, there needs to be geographic flexibility in managing ecosystems and associated watersheds, because they will need to migrate with temperature change and with sea level change.

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[1] Loáciga, HA. (2006) Modern-age buildup of CO_2 and its effects on seawater acidity and salinity, Geophysical Research Letters, 33, L10605, doi:10.1029/2006GL026305,

[2] Caldeira K, D Archer, JP Barry, RGJ Bellerby, PG Brewer, L Cao, AG Dickson, SC Doney, H Elderfield, VJ Fabry, RA Feely, J-P Gattuso, PM Haugan, O. Hoegh-Guldberg, AK Jain, JA Kleypas, C Langdon, JC Orr, A Ridgwell, CL Sabine, BA Seibel, Y Shirayama, C Turley, AJ Watson, RE Zeebe (in press) Comment on "Modern-age buildup of CO_2 and its effects on seawater acidity and salinity" Geophysical Research Letters.

3. What about the Arctic and Antarctic oceans, are those ecosystem particularly threatened by climate change and ocean acidification?

I am not an expert on polar ecosystems, but I will state what I do know. Polar ecosystems will experience the greatest temperature changes, and changes in sea ice extent, thickness and duration will doubly affect many organisms. Polar regions are also the first areas where ocean acidification will cause chemical changes that lead to surface waters that are actually corrosive to calcium carbonate shells and skeletons[3]. (Deep ocean waters are naturally corrosive to calcium carbonate, but the surface ocean everywhere on the globe is not acidic enough to dissolve shells. If atmospheric CO_2 concentration continues to increase at the present rate, within a few decades ocean acidification will cause surface waters in some polar regions to become acidic enough to dissolve organisms' shells. We do not yet know if non-shell forming organisms will be affected by this change.)

QUESTIONS FROM THE HONORABLE PATRICK KENNEDY

Regardless of whether or not we take actions to control and reduce green house gas emissions, wildlife and wildlife habitat and the ocean environment are going to change and adapt, often unpredictably, to a warming climate. Consequently, we should take steps now to develop strategies to allow for the future conservation of biodiversity and the maintenance of a healthy and resilient environment.

1. Keeping in mind that any transition to a new "Green Economy" will take decades to achieve and that most Members of Congress will want to limit unnecessary disruptions of social and economic systems, can you be more specific on what practical types of adaptive management strategies we should consider to mitigate the negative effects of climate change on our collective wildlife and ocean resources?

We all wish to avoid decisions that lead to a collapse of either our economy or our ecosystems—in reality they depend on each other. Although other scientists can speak to parts of this question in more detail, there are certainly some logical steps that can be taken to help mitigate negative effects of climate change on both terrestrial and marine resources. These steps fall into three categories:

a) Reducing greenhouse gas emissions to ecologically "safe" levels. This might include increasing energy efficiency, shifting our reliance on fossil fuel-based energy to cleaner technologies, and promoting human behavioral changes.
b) Identifying key areas for conservation. Sound conservation strategies are based on a better understanding of which regions are least/most vulnerable to climate change and other stresses. Which regions will benefit the most from conservation, and where should we concentrate our conservation efforts?
c) Concentrating on removing stresses that we can control, such as reducing overfishing, pollution, and land-based activities (e.g., deforestation) that negatively affect the marine environment. Marine organisms and ecosystems will thus have a better chance at managing the effects of climate change and ocean acidification.
d) Adopt economic evaluations that include of the value of "ecosystem services." Most ecosystems services are taken for granted: water purification, nutrient recycling, protection of our coastlines, supporting fisheries, etc. Rarely are these services taken seriously in economic evaluations, which may benefit some, but generally hurts all of us.

2. Should we be doing more to re-evaluate our current policies for land use planning and public acquisition of land for wildlife habitat? Should we be adopting a broader landscape and ecosystem-based approach for protecting wildlife?

Yes and yes. As stated above, the more we can reduce the manageable stresses on wildlife and ecosystems, the better they will be able to handle the less-manageable effects of climate change and ocean acidification. We can also do a better job at including climate change predictions in making these policies. Ecosystem-based management, particularly when it provides a means for species and ecosystems to migrate in response to climate change, is proving to be a sound means for protecting wildlife and the wild ecosystems that support them.

[3] Orr, JC, VJ Fabry, O Aumont, L Bopp, SC Doney, RM Feely, A Gnanadesikan, N Gruber, A Ishida, F Joos, RM Key, K Lindsay, E Maier-Reimer, R Matear, P Monfray, A Mouchet, RG Najjar, G-K Plattner, KB Rodgers, CL Sabine, JL Sarmiento, R Schlitzer, RD Slater, IJ Totterdell, M-F Weirig,Y Yamanaka, A Yool (2005) Anthropogenic ocean acidification over the twenty-first century and its impact on calcifying organisms, Nature, 437(7059): 681-686.

3. Finally, how might such ideas be applied to the ocean and coastal environment and the wildlife therein?

While policy-making is outside my expertise, in my opinion, our current policies for land use planning could be improved to focus more on habitat preservation rather than species preservation. This approach has been used increasingly in both the terrestrial and marine environments with good success.

QUESTIONS FROM THE HONORABLE HENRY BROWN, MINORITY RANKING MEMBER

1. Dr. Kleypas, in your written testimony you state that restoring the levels of carbon dioxide in the atmosphere to pre-industrial levels would restore the surface layers of the ocean to its pre-industrial state. How achievable or feasible is it to go back to pre-industrial carbon dioxide levels?

At the moment, this is not feasible, because it would require technology to remove CO_2 from the atmosphere. Such technology actually does exist, but it is not yet energetically efficient.

This point in my testimony was meant to highlight two points:

A) CO_2 diffuses across the air-sea interface from the air to the sea when atmospheric concentration of CO_2 is higher, but it diffuses from the sea to the air when the oceanic concentration of CO_2 is higher. Were we able to draw down the atmospheric concentration of CO_2, then CO_2 would exit the ocean into the atmosphere, thereby reversing the ocean acidification process.

B) While it presently seems infeasible to draw down CO_2 from the atmosphere, it should not be deemed impossible. In 1920, it was infeasible to put a man on the moon, but less than 50 years later, the U.S. achieved this remarkable feat. There are many other examples where the U.S. has demonstrated leadership and ingenuity that has greatly accelerated scientific and social progress.

2. Predicting specific aspects of global warming has been very difficult. Climate models predicted a global temperature increase of 1.5 degrees Celsius by the year 2000, six times more than that which has taken place. Modelers, at the time, argued that the heat generated by their claimed "greenhouse warming effect" were stored in the deep oceans. Has this theory been proven to be correct?

Based on observational data, the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) calculated a trend of 0.4-0.8°C increase in global surface temperature for the period 1901 to 2000. The most recent IPCC Assessment Report recalculated the trend for 1906-2006 to be 0.56-0.92°C.

Analysis of ocean temperature observations taken since the 1960's indicates that the oceans are warming at the surface (absorbing some of the heat from the atmosphere), and ocean currents are transporting some of that heat to deeper parts of the ocean. Comparisons of model predictions with observations indicate that the warming signal in the oceans is well-represented in several global climate models [4]. One estimate of the increased heat content of the oceans between 1955 and 1998 (14.5×10^{22} J) would account for some 84% of the increase in heat content for the total Earth system [5]; another estimate of the increase in ocean heat content between the decades 1957-66 and 1987-96 is somewhat less ($12.8 \pm 8.0 \bullet 10^{22}$ J) [6].

3. The March 30, 2007, issue of Science contains a research article that shows calcifying coral species, in the absence of conditions supporting skeleton building, maintained basic life functions as skeleton-less forms and returned to skeleton building when conditions returned to normal. Is this research promising with regard to the survival of corals over the long-term?

Yes and no. This research supports previous studies that predicted that some coral species (those most closely related to a coral-like group of organisms that do not have skeletons) may have the ability to survive as "naked" corals, and also that this is what allowed some species to survive the Cretaceous-Tertiary extinction event (the mass extinction event that wiped out the dinosaurs 65 million years ago).

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[4] Barnett, TP, DW Pierce, KM AchutaRao, PJ Gleckler, BD Santer, JM Gregory, and WM Washington (2005) Penetration of human-induced warming in to the World's oceans. Science 309: 284-287.

[5] Levitus, S, J Antonov, and T Boyer (2005), Warming of the world ocean, 1955-2003, Geophys. Res. Lett., 32, L02604, doi:10.1029/2004GL021592.

[6] Gouretski, V, and KP Koltermann (2007), How much is the ocean really warming?, Geophys. Res. Lett., 34, L01610, doi:10.1029/2006GL027834.

However, the survival of such "naked corals" in the wild is questionable, because the functions of the skeleton (protection from currents and predation; ability to grow upward toward the light; extension above the substrate; etc.) would be lost. Even if some species were able to survive such skeletal loss, they would no longer build reefs, so that the ecosystem itself would lose its ability to support many other species or the ecosystem services that coral reefs provide (please see the response to Congressman Brown's question 23 for some examples of these services).

4. It has been reported that sea water expands when warm. How much of the sea level rise predictions take into account thermal expansion of sea water? (10 percent of the sea level rise estimated to be from glacial runoff).

I am not an expert on sea level rise, and I will answer only briefly. Because the warming of the ocean lags behind atmospheric CO_2 concentration increases, sea level rise from thermal expansion would continue for centuries after atmospheric CO_2 concentrations are stabilized, because of the time required to transport heat to the deeper parts of the ocean. That is, as rising air temperatures from increased CO_2 in the atmosphere warm an ever increasing volume of sea water at greater depths, this growing volume of warmer water will continue to expand, thus contributing to ongoing sea level increases. This also means that the contribution of thermal expansion to overall sea level rise changes over time; but in general, thermal expansion accounts for an estimated one-third to one-half of the observed sea level rise. Projections of sea level rise take into account estimates of future thermal expansion, as well as contributions from melting glaciers and ice caps, the Greenland ice sheet, and the Antarctic ice sheet. Recent apparent accelerations of the rate of ice discharge from the Greenland ice sheet are also taken into account in the current projections of sea level rise in the IPCC AR4, though our understanding of this process is limited since we have just recently begun to see such apparent accelerations. Therefore, the IPCC AR4 concludes that larger values of sea level rise cannot be excluded.

5. It has been reported that the typical breakdown of carbon dioxide in the atmosphere is 57 percent from the ocean, 19 percent from decaying vegetation, and 19 percent from plant and animal respiration. Do you agree with this breakdown? If not, what is it?

I am not sure what this question is asking, so I have included a figure[7] that illustrates the relative sizes of the carbon reservoirs, as well as the fluxes of carbon between those reservoirs. From this information one can derive the relative importance of the reservoirs and fluxes to the atmospheric concentration.

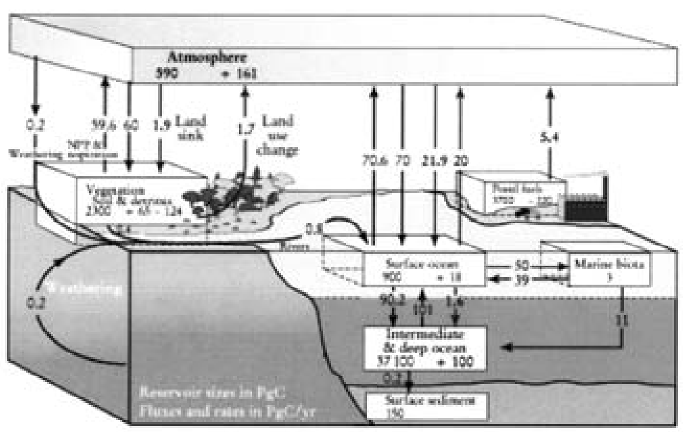

Figure: GLOBAL CARBON CYCLE: Arrows show the fluxes (in pentagram of carbon per year) between the atmosphere and its two primary sinks, the land and ocean, averaged over the 1980s. Anthropogenic fluxes are in red; natural fluxes in

[7] Sarmiento, JL and N Gruber (2002) Sinks for anthropogenic carbon, Physics Today, 55(8), 30-36, 2002.

black. The net flux between reservoirs is balanced for natural processes, but not for anthropogenic fluxes. Within the boxes, black numbers give the preindustrial sizes of the reservoirs and red numbers denote the changes resulting from human activities since preindustrial times. For the land sink, the first red number is an inferred terrestrial land sink whose origin is speculative; the second one is a decrease due to deforestation. Numbers are slight modifications of those published by the Intergovernmental Panel on Climate change. NPP is net primary production. From Sarmiento and Gruber (2002).

6. It has been reported that current carbon dioxide levels are 370 parts per million and pre-industrial revolution levels of carbon dioxide were 280 parts per million. Do you agree with these levels? Interpretations of past geological levels of carbon dioxide have been reported to be 1000 parts per million without adverse effect on species. Do you agree? If 1000 parts per million were not cause of adverse effects, how is 370 parts per million a problem?

Current carbon dioxide levels are 383 parts per million (ppm). I agree with the estimate that the pre-industrial level was 280 ppm, and that atmospheric CO_2 levels were much higher (e.g. 1000 ppm) in the geological past. Whether such high CO_2 levels caused adverse effects on species depends on several factors, but mainly on whether atmospheric CO_2 was rising and if so, how fast.

Your question is a good one. It is a common point of confusion and one that requires a brief explanation in ocean chemistry. Ocean pH, or acidity, is determined not only by CO_2 concentration, but also by ocean alkalinity. Ocean alkalinity is in simplest terms, the concentration of positively charged ions of calcium, potassium, sodium, etc., that accumulate in the ocean from the weathering of rocks. An increase in ocean alkalinity causes pH to increase, and vice-versa. During those geologic periods when CO_2 levels were maintained at much higher levels, it is likely that ocean alkalinity was also elevated. This is because the rates of weathering (the breakdown and dissolution of rocks) would have increased. On land, rates of weathering would increase because of 1) a warmer climate, and 2) elevated atmospheric CO_2 levels would have caused rain to be more acidic which would dissolve rocks more quickly. In the ocean, increases in ocean acidity cause calcium carbonate sediments in the deep sea to dissolve. Both the land and ocean weathering processes deliver more alkalinity to the oceans. While CO_2 levels can increase rapidly (such as through rapid onset of volcanic activity, a rapid release of methane, or fossil-fuel burning), weathering processes can increase ocean alkalinity only slowly. Thus, a gradual increase in atmospheric CO_2 is matched by an increase in alkalinity, but a rapid increase in CO_2 causes an increase in ocean acidity (i.e., pH decreases) until weathering brings the system back into balance. These balancing feedbacks occur on long timescales (thousands of years) and help maintain stable acidity in the ocean.

Aside from the present, we know of at least one period in Earth history when ocean acidification has happened before. Fifty-five million years ago, a rapid increase of carbon to the atmosphere was accompanied by a rapid decrease in calcium carbonate deposition in the oceans. This was accompanied by dramatic dissolution of calcium carbonates in the deep ocean, as well as by changes in ocean biota (some species apparently went extinct, but the changes in ocean biology during this event have not been well examined). After about 50 thousand years, ocean pH appeared to have recovered to the levels that had occurred before the rapid CO_2 increase.

7. It is generally agreed upon that modern-day corals first started to appear about 200 million years ago. During the past 200 million years, many large-scale changes have occurred to the earth and its climate—continents have drifted about, sea levels have risen and fallen by several hundreds of feet, ice sheets have come and gone, carbon dioxide levels have fluctuated from below today's levels to as much as 10 times as high as today and the earth's temperatures have fluctuated by 10 or more degrees Fahrenheit—and many of these types have changes have, from time to time, occurred rapidly (for example, sea level and temperature changes at the termination of ice ages). Yet through it all, high acid oceans/low acid oceans, warm oceans/cold oceans, high sea levels/low sea levels, corals and coral reefs have persisted—as evidenced by there existence today. They seem rather responsive and adaptive. Is it possible that the reason you find that coral appear to be very sensitive to climate change is that many studies have taken place in the laboratory under carefully controlled conditions that do not well-capture the vast array and complexity of the conditions (including diversity across species as well as genetic diversity within species)?

It is true that the ancestors of "modern-day" corals (taxonomic order Scleractinia) did appear around 240 million years ago. There is also evidence that skeleton-building in these corals may have waxed and waned with fluctuations in seawater chemistry over geologic time[8],[9]. The study mentioned in Congressman Brown's question 3[10] is one example of experimental evidence that skeletal formation in corals is sensitive to changes in ocean chemistry. This result is consistent across dozens of such experiments, and across dozens of species. But we agree that the experiments are limited and should be conducted on many more species and under more natural conditions. So far, there has been limited funding to do this but there is a growing call from the scientific community to conduct more such experiments.

The evidence that at least some corals can survive without skeletons is good news when considering their potential to survive ocean acidification. However, given that their skeletons provide some function, these corals will not be functioning within the ecosystem as they are in skeletonized form. If we are to assume the corals will change their existence to being in anemone-like, then the basis for reef ecosystems and reef building will be lost nonetheless (also see the response to Congressman Brown's question 3).

Other lines of evidence—not just laboratory experiments—support the hypothesis that skeletal growth in corals as well as reef-building will decline as ocean acidification proceeds. The present-day distribution patterns of both tropical reefs and cold water corals. While tropical corals can and do occur outside the tropics and subtropics, they apparently do not produce enough skeletal material to build reefs. Cold water corals are related to tropical corals, but these also seem restricted to waters above the zone where their skeletons would dissolve. Finally, the geologic record illustrates the persistence of corals through geologic time but also illustrates that corals waxed and waned in concert with changing environmental conditions, suffered mass extinctions, and re-evolved. The evolutionary history of corals does extend back several hundred thousand years, but modern-day corals evolved from a few species that survived the Cretaceous-Tertiary mass extinction 65 million years ago. The coral record was also interrupted by long intervals (millions of years) where corals were few and did not build reefs. Corals did not gain status as major reef-builders for several million years after the Cretaceous-Tertiary mass extinction.

8. How can you explain the persistence of coral species and coral reefs over the course of the large and sometime rapid climate changes that have occurred over the past 200 million years?

Please see the response to Congressman Brown's question 7.

In short, coral species and reefs have waxed and waned over geologic time in concert with changes in climate. Indeed, reef ecosystems seem to be the first to collapse during a mass extinction event and the last to recover[11]. Scleractinian corals were

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[8] Stanley, GD and DG Fautin (2001) The origins of modern corals, Science, 291(5510): 1913-1914.

[9] Medina, M, AG Collins, TL Takaoka, JV Kuehl, JL Boore (2006) Naked corals: skeleton loss in Scleractinia, Proceedings of the National Academy of Sciences. U.S.A., 103: 9096-9100.

[10] Fine, M and D Tchernov (2007) Scleractinian coral species survive and recover from decalcification. Science, 315: 1811.

[11] Stanley, G.D. (ed.) 2001. The History and Sedimentology of Ancient Reef Systems, Vol. 17, Topics in Geobiology, Kluwer Academic / Plenum Publishers, New York, 458 pp.

not the dominant reef builders until the Late Triassic (> 200 million years ago), and experienced major extinctions around 100 million years ago, and again 65 million years ago. While some species did survive these extinction events, reefs did not re-develop for millions of years. As stated by Stanley (2001) "The public may fail to be concerned about the predicted reef decline, pointing to the fact that throughout their history, reef ecosystems have inevitably recovered. It is relevant, however, to be reminded of the magnitude of time. Reef eclipse intervals of the Phanerozoic [540 million years ago through the present] spanned millions of years, and millions of more years were need before reef ecosystems recovered."

9. How did coral manage during the times when atmospheric carbon dioxide concentrations were several times higher than they are today—conditions that existed for many million of years?

A common misconception is that carbon dioxide concentration is the only variable controlling ocean pH, and that when atmospheric carbon dioxide concentrations in the past were several times higher than they are today, then the ocean pH would have been correspondingly low. As explained in the response to a previous question 6, ocean alkalinity is also a factor that controls ocean pH. Increased atmospheric CO_2 leads to increased weathering rates on land which leads to higher alkalinities in the ocean, therefore buffering the effects of increased CO_2. In the ocean, increases in ocean acidity are similarly buffered by the dissolution of calcium carbonates in the deep ocean. Both of these weathering processes require thousand to millions of years. For those periods when atmospheric CO_2 concentrations remained much higher than today for millions of years, then the carbonate chemistry of the ocean probably maintained pH at a constant equilibrium value, or changed slowly enough for organisms to adapt.

10. Are there not scientific studies which suggest that present day corals are far more adaptive to both changes in temperatures (and coral bleaching events) and to changes in ocean acidification then you assume, and that indeed, rising temperatures may in fact lead to faster coral growth? That corals can respond to rising temperatures and resist bleaching by changing their algal relationships? That some corals can also adapt to changing ocean acidification by altering the way that they produce their shells? Isn't it likely, based simply upon the evidence that coral exist today that the real world is far more adaptive and changeable than can be gathered through limited observations and controlled experiments in laboratories?

As you suggest, there is evidence that skeletal growth in corals is also enhanced by increases in temperature. In fact, sclerochronological records (analogous to tree rings) from some corals indicate an increase in skeletal growth as sea surface temperatures have warmed. However, temperature-induced increases in skeletal growth are considered short-lived for two reasons. First, the calcification rate in a coral is highest near the maximum temperature that the particular coral experiences. At temperatures lower or higher than this maximum, the calcification rate declines. That is, as temperatures approach this maximum, the coral calcification rate will increase, but once the temperature exceeds that maximum, the rate will decline. Second, increasing sea surface temperatures, at least at the current rates of increase, cause coral bleaching that is often followed by coral death. Calcification rates in bleached corals usually ceases altogether.

This "adaptive bleaching hypothesis" is based on the observation that algae that repopulate bleached corals can different from the original algae and can be more temperature tolerant. This is believed to be a mechanism by which symbiont-bearing corals (most corals on tropical reefs) can adapt to environmental change. This has been observed in the lab and the field, but it has not been proven as an effective adaptation, at least at the current rate of temperature increase. The strongest evidence of the limited efficacy of adaptive bleaching is the observation that coral bleaching has occurred repeatedly in many regions, often within the same coral colonies.

To my knowledge, there is no evidence that corals can effectively adapt to ocean acidification by altering the way that they produce their skeletons.

The evidence that corals survive today is not testament that the real world is more adaptive than what laboratory experiments show. The environmental changes that corals are experiencing today are much greater than they have experienced for hundreds of thousands to millions of years.

11. How do your future ocean acidification scenarios and time lines related to the rates of increasing atmospheric carbon dioxide concentrations compare to the actual observed rates of carbon dioxide concentration increase?

My main assumption regarding future increases in atmospheric carbon dioxide is that carbon dioxide concentrations will reach double the preindustrial concentrations by the end of this century. This is well within the suite of predictions of atmospheric CO_2 concentration assuming the "business as usual" scenario as well as the suite of SRES scenarios. Even if the growth in atmospheric CO_2 is held at 0.5% per year, atmospheric CO_2 concentration will reach 560 ppm (i.e., double preindustrial levels) by the year 2085.

Because the surface ocean is in direct contact with the atmosphere, and because the concentration of CO_2 in the surface ocean takes only about a year to equilibrate with the atmospheric concentration, I assume that ocean acidification tracks atmospheric CO_2 concentration. I also account for the effect of ocean warming on ocean acidification; for example, I assume that the surface ocean will be 2δC warmer under doubled preindustrial concentrations.

12. Is the current distribution of corals and coral reefs more limited by cold water or warm water? If the oceans warm up, won't corals expand their ranges into waters that were previously too cold? Are there any regions of the world's oceans that are too warm for corals? In previous periods during the past 200 million years, the most of which was warmer than today, was the range of corals more limited or more expansive than today?

The current distribution of tropical coral reefs shows that reef development is limited to regions that remain above about 18δC year round. As ocean temperatures warm, we can expect some corals to expand their geographic distribution. There is at least one documented case of a coral species expanding its range northward along the Florida coast [12]. We do not know of any regions that are too warm for corals. Corals in the Red Sea, for example, are adapted to temperatures warmer than elsewhere. This adaptation to such high temperatures is believed to have occurred over evolutionary time scales. But even these corals have bleached in recent years when warming exceeded the temperatures to which they are adapted. Bleaching can occur anywhere, in both the coolest and warmest waters of the tropics, if temperatures exceed what the local corals are used to.

The geographic distribution of scleractinian corals has changed over geologic time, probably due to many factors (temperature, salinity, the concentrations of calcium and magnesium in seawater, competition with other species, etc). For example, corals were the dominant reef-builders during the early Cretaceous Period (one of the periods thought to have very high CO_2 levels), but gradually declined near the mid-Cretaceous, and by the late-Cretaceous appeared to have been eliminated from equatorial regions. It is unclear whether they were limited more by environmental factors (e.g. temperature, nutrients) or by competition with a particular type of bivalve that was widespread during the Cretaceous but went extinct along with the dinosaurs. Certainly, corals have expanded their ranges during warm periods of the past, but because temperature is not the only factor that limits corals, it is impossible to generalize the relationship between global temperature and coral distribution patterns.

13. How did corals and coral reefs survive the rapid and large climate changes that have characterized that past 4 or 5 ice ages? What percentage of the world's distribution of coral reefs are located along the U.S. coasts?

Relative to the predictions of sea level rise for this century, sea level changes of the past 4-5 ice ages were far more dramatic, including a total sea level rise of some 120 m. Coral reefs managed these changes with apparently very little change in their species make-up [13]. Coral reefs have typically thrived during periods of sea level rise. One reason is that once a reef reaches the surface, water circulation becomes restricted and coral growth is then limited to the edges of the reef. The sea level rise predicted for this century is not considered an important threat to coral

[12] Precht, WF and RB Aronson (2004), Climate flickers and range shifts of reef corals. Frontiers in Ecology and the Environment 2:307-314.

[13] Pandolfi, JM and JBC Jackson (2006) Ecological persistence interrupted in Caribbean coral reefs, Ecology Letters, 9(7): 818-826.

reefs, except in areas where reefs grow in close proximity to areas where flooding will result in decreased water quality.

Current and predicted rates of temperature change in the tropics, however, were much more rapid than those during the ice-age fluctuations. During the peak of the last ice age (about 20 thousand years ago), sea surface temperatures in the tropics were probably about 1-4°C colder than today [14]. The warming of the tropical ocean to near the present-day temperatures occurred over several thousand years. The current and predicted rates of ocean warming are several δC over a few decades, which is much faster rate of change than occurred during the ice ages. In summary, the absolute change in temperature is not as important as the rate of that change. The current rate of warming exceeds the rate at which corals and other organisms can adapt.

I believe that around 5% of the world's coral reefs exist in U.S. waters.

14. Aren't there are whole lot of factors that can cause coral reef decline? Factors such as pollution, sedimentation, over fishing, boating and shipping injuries—that are often the case of overdevelopment and poor land use planning and oversight?

Yes. All of these factors can and do cause coral reef decline. And as you state, many of these are due to poor land use planning and oversight. This is why many coral reef scientists and managers recommend doing more in terms of mitigating these controllable impacts.

There is little doubt, however, that the current warming trends in the ocean are affecting coral reefs, because many reefs that are relatively pristine and isolated from the direct impacts listed above have experienced coral bleaching. Please see the response to Congressman Brown's question 15 for more on this topic.

15. Oftentimes, the effects of global warming are cast as potentially being the proverbial straw that breaks the camels back when it comes to coral reefs? Do you think that placing restrictions on carbon dioxide emissions in the United States in an effort to modify global climate that in turn may perhaps lighten the load of a camel that is primarily owned and overloaded by other countries is a fair and/or effective strategy? If coral reefs along U.S. coastlines are currently limited because our coastal waters are too cold, then would a slight warm-up be good for attracting coral reefs (and all the benefits that accompany them, as you all outlined fisheries, tourism, etc.) to the U.S. coastal areas?

Even if other stressors on coral reefs are eliminated, coral bleaching and ocean acidification will continue to affect them. Some of the world's most pristine reefs have suffered high mortality from coral bleaching. This does not mean that we shouldn't reduce the other stressors that are mentioned in Question 14, because it appears that following significant mortality (either from bleaching, hurricanes, or some other acute damage), coral reef recovery is more likely in regions without these additional stressors.

16. You testify that coral reef ecosystems are "among the most diverse and biologically complex ecosystems on Earth...". If they are so diverse, is it realistic to assume that a change in water temperature of just one degree will wipe out all coral reefs?

I agree with the statement that coral reef ecosystems are "among the most diverse and biologically complex ecosystems on Earth..." I am not familiar with the assumption that "a change in water temperature of just one degree will wipe out all coral reefs." Based on the current rate of bleaching-related coral loss, there is certainly evidence that a 1δC change in temperature, at least at the current rate of the increase, will adversely impact coral reefs. The temperature increase that will cause "all coral reefs" to be "wiped out" depends both the rate of the warming, and the ability and rate at which corals can adapt.

17. There is a lot of discussion about the detrimental effects of warm water on corals, yet corals have survived for millions of years. Are the corals becoming less resistant to water temperature changes? If so, why is this so?

There is much discussion about the detrimental effects of warm water on corals because of the dramatic increase in coral bleaching events, almost all of which are

[14] Barrows, TT and s Juggins (2004) Sea-surface temperatures around the Australian margin and Indian Ocean during the Last Glacial Maximum, Quaternary Science Reviews 24: 1017-1047.

linked to increases in temperature. Corals have survived millions of years, but as discussed in several preceding questions, they have also suffered major extinctions. Corals are not becoming less resistant to water temperature changes, and indeed, they can adapt to changing temperatures (as evidenced by the fossil record). What is killing the corals is the rate of the temperature change.

18. Are some species of corals more resistant to temperature change than others? Are these types of resistant corals likely to move into areas currently populated by less-resistant corals?

Yes, some species are more tolerant of temperature changes. It is possible that some of the more temperature-tolerant corals will grow where others have died. It is also possible that non-coral species will grow in these areas.

19. Some researchers have focused on the El Nino Southern Oscillation (ENSO) as a threat to corals. Isn't ENSO a naturally-occurring event that has been documented for decades? If so, why is the threat considered so critical now?

Yes, ENSO is a naturally-occurring event that has been documented for decades and probably for thousands of years (based largely on temperature records obtained from coral skeletons). ENSO events are considered a major threat to coral reefs now because:

1) Climatic changes in temperature, wind patterns, cloud cover, circulation patterns, etc., can create conditions that are conducive to coral bleaching events. These conditions are further heightened by the background increase in sea surface temperature due to the greenhouse effect.
2) While mass coral bleaching events are increasing in general, regardless of whether El Niño conditions exist, coral bleaching during ENSO years are more widespread and deadly. During the 1997-1998 ENSO, for example, an estimated 16% of the world's coral reefs were extensively damaged by bleaching [15].
3) The ENSO events in 1982-83 and 1997-98 had major impacts on coral reefs worldwide. These two events were some of the strongest events on record. Models show that El Niño events will continue in a future warmer climate (i.e. they won't go away), but their future amplitudes and frequencies may become much less predictable.

20. You state that NOAA has climate change time series that go back decades. Are fluctuations and regime shifts common in the ocean environment even in short time series (such as since the 1950s)?

I believe this is a question for Dr. Eakin and NOAA, but I will briefly respond. Short time-series are usually not sufficient alone to determine whether "fluctuations and regime shifts" are common in the ocean environment. It depends on what kind of fluctuations one is interested in. Some organisms and ecosystems with rapid life cycles can undergo very rapid changes in populations, and or experience strong fluctuations in response to large-scale climate oscillations that occur over decades or less. Other ecosystems, such as coral reefs, are much more persistent. Cores taken through coral reefs that go back many thousands of years do not show the kinds of changes in coral communities as we have seen over the past 2-3 decades. We generally rely on many types of data, not simply the last few decades of time-series data, to determine whether a change in a marine ecosystem is natural or not.

21. Are time series that show only a few decades really useful in determining historical patterns?

Please see the response to question 20 above. Scientists tend to use information across multiple time-scales and multiple resolutions. High resolution records kept by humans are possible today, and provide valuable information regarding small changes in climate and over small spatial scales. We can also obtain records about climate from natural recorders of climate, such as ice cores, coral banding, tree rings, and sediment cores, to name a few. Reconstructions of climate beyond the human-kept record must rely on these natural records, so much effort is made to validate them with the human-collected record, and to cross-validate them with other historical records. No time-series has revealed coral reef ecosystem changes comparable to those of the last several decades.

[15] Wilkinson, C. 2000. Status of Coral Reefs of the World: 2000. Global Coal Reef Monitoring Network and Australian Institute of Marine Science, Townsville, Queensland, Australia, 363 pp.

22. Weren't there coral reefs where the Great Lakes now sit? What caused these coral reef populations to die off?

I believe you are referring to the reef complexes of the Silurian (408-438 million years ago) and Devonian (360-408 million years ago) Periods. These reefs included some corals that were somewhat related to corals we have today, but were still quite different and are now extinct. The modern day corals had not yet evolved (see Congressman Brown's question 7). The exact reasons for the major extinction at the end of the Devonian are not known; global cooling, sea level drop, and meteorite impacts have all been suggested as causes.

23. Because coral reefs are so productive ecosystems, partially because they provide hiding places for other animals, can their functions be created artificially?

Replacing coral reefs with artificial structures is like replacing a rainforest with artificial trees. Yes, some birds may sit in the trees (even if there is no food for them), but the services the rainforest provides to the functioning on this planet will be lost.

The ecosystem services provided by coral reefs are often not obvious but they are many. Reefs provide not only spatial habitat for fish, but nutrition for those fish, cycling of nutrients, buffering of seawater chemistry, coastal protection (reefs are much better than man-made structures), sand production that maintains beaches and supports other important habitats such as seagrass beds and mangroves, biodiversity (which in turn supports ecosystem stability and holds promise for the discovery of many medicinal compounds), etc.

The term "artificial reef" may be misleading in that it implies that coral reefs can be created artificially. In short, a structure can be artificially created, and at times this can stimulate natural colonization of corals and reef growth, but the structure alone does not replace the many coral reef functions.

24. If sea surface temperatures rise, is it likely that some coral reefs will begin moving into deeper water where it is slightly cooler? How deep can corals reside and still make use of sunlight?

Coral reefs will probably not "begin moving into deeper waters," but those that currently exist in deeper waters may be less affected by coral bleaching than are shallow water reefs. Coral bleaching tends to affect shallow water corals more than deep corals, but this has not always been the case.

The deepest records for light-gathering corals are about 120-140 m; these records are from a few individual corals from the clearest waters of the Red Sea. Normally, corals are limited to 30 m and less. The coral communities of Pulley Ridge off the west coast of Florida occur in waters 58 to 75m deep, but it is not clear whether the corals in these communities are reproductively viable, nor whether they contribute to reef growth or not. Coral reef productivity and reef-building capacity diminish greatly with depth, because light attenuates very rapidly with water depth (even in the clearest ocean water, only about 10% of light hitting the surface of the water reaches 90 m depth). So for corals that do exist in deeper water, their capacity to build coral reefs is low. Also, the types of corals that can persist in deeper waters tend to be different species than those in shallow water. For example, the most prolific "reef-building" coral in the Caribbean, the elkhorn coral (Acropora palmata), is restricted to about 10 m water depth, and so this important species would not be able to find refuge in deeper waters.

25. Do you or have you (or your organization) received any funding from the Pew Charitable Trust or the David and Lucille Packard Foundation? If so, please elaborate.

I was a co-author on two Pew Climate Change reports:

Kennedy VA, RR Twilley, JA Kleypas, JH Cowan, Jr. and SR Hare (2002) Coastal and Marine Ecosystems and Global Climate Change: Potential Effects on U.S. Resources. Pew Center for Global Climate Change, Arlington, VA. 52pp.

Buddemeier RW, JA Kleypas and R Aronson (2004) Coral Reefs and Global Climate Change. Potential Contributions of Climate Change to Stresses on Coral Reef Ecosystems, Pew Center for Global Climate Change. 42 pp.

I was contracted through Stratus Consulting in Boulder, Colorado. For the first report I received $1800 for my contribution, and for the second, I received $3000.

26. Are you currently a party to any law suit against the Department of the Interior or the Department of Commerce (or any of the agencies within these departments)? If so, please describe.

No.

QUESTIONS FROM THE HONORABLE WAYNE GILCHREST

1. If paleo-records show that corals existed in the past under high atmospheric CO_2 concentrations, why is it a problem now?

Corals have existed in the past under high atmospheric CO_2 concentrations. These conditions were warmer than today, but were not necessarily more acidic. Corals can and do adapt to warmer temperatures. Corals in the Red Sea, for example, can tolerate much warmer temperatures than most other corals. Their ability to tolerate warmer temperatures was probably acquired over long periods of time, say many centuries to millennia. Note, however, that even these temperature-tolerant corals experience bleaching when the local temperatures exceed the normal maxima. This means that their rate of adaptation to increasing temperature is exceeded by the rate of that temperature increase. In the past, corals that existed in high temperature waters were adapted to those temperatures. When temperature changes were too rapid for them to adapt, then they probably died. There are several periods in Earth history when corals suffered major extinction, indicating that they did not adapt to some environmental change.

Even with much higher atmospheric CO_2 concentrations in the past, the oceans may not have been more acidic than they are today. A common misconception is that carbon dioxide concentration is the only variable controlling ocean pH, and that when atmospheric carbon dioxide concentrations in the past were several times higher than they are today, then the ocean pH would have been correspondingly low. As explained in the response to Congressman Brown's question 6, ocean alkalinity is also a factor that controls ocean pH. Increased atmospheric CO_2 leads to increased weathering rates on land which leads to higher alkalinities in the ocean, therefore buffering the effects of increased CO_2. In the ocean, increases in ocean acidity are similarly buffered by the dissolution of calcium carbonates in the deep ocean. Both of these weathering processes require thousand to millions of years. For those periods when atmospheric CO_2 concentrations remained much higher than today for millions of years, then the carbonate chemistry of the ocean probably maintained pH at a constant equilibrium value, or changed slowly enough for organisms to adapt.

2. Among the various effects of climate change to wildlife and the oceans, are there issues that are more pressing than the others? Why?

I will answer this from an ocean perspective. In my opinion, the two pressing effects of climate change are increasing temperature and ocean acidification. Increasing ocean temperature is obviously harming coral reefs directly by causing coral bleaching and massive die-offs. It is also indirectly affecting them by increasing their vulnerability to coral diseases. These are acute stresses on coral reefs. In contrast, ocean acidification is a chronic stress that does not kill coral directly, but rather changes their ability to function normally within a reef system. Both of these are becoming increasingly important over time.

In other marine ecosystems, such as ice-dependent polar systems, increasing temperature is obviously a very important threat that affects marine organisms in both direct and indirect ways. While the effects of ocean acidification on many marine ecosystems are still poorly known, we do know that ocean acidification is occurring and will continue to occur in lock-step with increases in atmospheric carbon dioxide.

3. In the U.S., as plant and animal species migrate north and to higher elevations, what does that mean for the regions they leave behind? For instance, it has been said that some U.S. states that border Canada might actually benefit from the next few decades of climate change, but what will it mean for the states further to the South, and especially those on the coast?

In the North American coastal marine environment, some species are migrating northward in response to warming temperatures. In some cases, there may be a simultaneous elimination of individuals from waters that are too warm (a range shift). In other cases some individuals are simply moving further away from the normal distribution (a range expansion). The main problem with any of these movements, particularly when many species are involved, is that normal ecosystem interactions are disrupted. This is commonly referred to as a "pulling apart" of ecosystems. We can expect the natural balances in these ecosystems to be upset (changes in predator-prey relationships, mismatches in timing of plant/animal interactions, exposure of some ecosystems to new species, etc.). Over the last few decades, we have several examples of single invasive species causing rather large and surprising changes in ecosystems. With climate change, the cumulative effects of multiple species moving into new territories, or the loss of multiple species from specific areas, will be even more difficult to predict.

4. How do shifts in habitat range of plants and animals affect human interests such as agriculture or the spread of invasive species and diseases? How can we adaptively plan for such changes?

As mentioned in the previous question, shifts in the distributions of multiple species will both pull the normal species associations apart, and force new species to live together. Symbiotic and opportunistic relationships between species (e.g., bees pollinating flours, birds timing their nesting to coincide with pest outbreaks) and seem so natural that we take them for granted. But many of these have taken thousands to millions of years to evolve, and there is already evidence that climate change is disrupting some of these relationships.

Adaptive planning for such changes requires close monitoring of these systems to detect if and when key ecosystem components will be threatened or key species relationships will be disrupted. Farmers and fisherman are often the first alarms when their ecosystems are experiencing change. Adaptive planning also means having strategies in place for dealing with such changes, such as effective means for controlling invasive species or diseases. Some of these plans should include geographic flexibility as well, to allow organisms to migrate with climate change. In coastal systems, the need for some ecosystems to migrate inland with sea level rise will conflict with human interests to protect property.

5. The IPCC reports with 80% certainty that the changes in water temperatures, ice cover, salinity and ocean circulation are impacting the ranges and migration patterns of aquatic organisms. How will this affect management and use of these resources, and how can we prepare for any changes?

This question is closely related to question 4 above, in which you mention the use of adaptive management. The best way to prepare for these changes is to have flexible management options in place that consider a wide range of factors in making decisions. I am not an expert on this topic, but there is a growing body of literature on this type of ecosystem management.

6. In the Chesapeake Bay, we are losing marshland to rising sea levels. Can you talk about what is happening to coastal wetland areas in other areas of the country and what that is doing to their ecosystems and the local economies that depend upon these natural resources?

I refer to my fellow panelists who are knowledgeable about marshlands to respond to this question.

7. What role do marshlands play in sequestering carbon? Is marsh restoration a viable alternative in carbon sequestration?

Although I have some familiarity with salt marsh ecosystems, I am sure that my colleagues will provide a more complete answer to your question. However, I refer you to a recent review of wetland resources by Sedler and Kercher [16]. Wetlands store large amounts of carbon, particularly in their soils. Salt marshes and mangroves appear to be particularly good at carbon sequestration, because they rapidly accumulate C for long periods of time. Marsh restoration therefore seems to be a sound carbon sequestration option, particularly because it will simultaneously restore so many other ecosystem services that marshes provide. Because wetlands have accumulated so much carbon over time, their destruction can release large amounts of carbon to the atmosphere, so preserving them will prevent this carbon from being released to the atmosphere.

8. The latest IPCC report warns that ocean acidification poses a threat to coral reefs and shell-forming organisms that form the base of the aquatic food chain. But the report says more study is needed to determine the full scope of the threat. What do we know about the potential impacts to U.S. coastal ecosystems today and how quickly is our understanding of acidification improving? What can Congress do to improve upon this understanding? Do we know enough to act?

First, given the high risk of ocean acidification to marine organisms, in my opinion we do know enough to justify actions to reduce carbon dioxide emissions. The effects documented so far are rarely benign and have been far-reaching. We know the most about the effects of ocean acidification on coral reefs. Even if corals eventually adapt to lower pH (there is no evidence that they do), coral reefs will still lose their ability to maintain their structures because lower pH will cause them to dis-

[16] Zedler, JB and S Kercher (2005) Wetland resources: status, trends, ecosystem services, and restorability, Annual Review of Environmental Resources, 30: 39-74.

solve faster. This type of "carbonate budget" problem may affect other benthic ecosystems as well, such as oyster banks and mussel beds.

The body of ocean acidification research has grown slowly, mostly because it is a relatively new issue that has taken time to garner the necessary support from scientists. Ocean acidification was solidly put forth in the mid to late 1990's, but such issues usually take a few years to be vetted by the scientific community. Now ocean acidification has broad scientific acceptance as a priority issue that warrants much more research.

Congress can certainly speed the process of answering the many questions about ocean acidification and its impacts on coastal ecosystems by (1) supporting scientific research and observations in these areas, (2) supporting the training of the next generation of scientists who will take up this research topic, and (3) encouraging this research be coordinated across multiple agencies to reduce duplication of effort and to take advantage of existing ocean observation network and data bases. NSF, NOAA, NASA and the USGS are four such agencies that are interested in pursuing observations and research that will inform decision makers about the consequences of ocean acidification, and what can be done to protect our resources. In the short term, there is

9. What additional resources or tools will the Fish and Wildlife Service and National Marine Fisheries Service need to adequately prepare and address the impacts of global warming on wildlife over the next decade?

I believe this question is best posed to personnel at the Fish and Wildlife Service and the National Marine Fisheries Service.

10. We've heard a lot about the polar bear and the petition to list the species under the Endangered Species Act (ESA). Opponents of listing claim that the effects of global warming are in fact unclear. What evidence is there that global warming is already having a dramatic effect on the species across its range? How will an ESA listing help polar bears?

I am sure that some of the other panel members are better informed on this issue. From an ecological standpoint, I can say that the observed and predicted changes in the Arctic are so dramatic that it seems certain that the habitat supporting polar bears is declining both spatially and in quality, and will continue to do so.

11. Are there factors that exacerbate the impacts of climate change on corals and coral reef ecosystems?

Yes. Because coral reefs live in shallow water and often near coastlines, they are subject to a multitude of stresses. These have been well documented. Coral reef scientists that were surveyed about the various threats to coral reefs in their regions identified potentially controllable threats such as: overfishing, coastal development, sedimentation, nutrient enrichment, and mangrove destruction as major threats, but also identified such issues as the lack of laws, law enforcement, and education as major factors impacting coral reefs [17]. Although climate change effects such as coral bleaching can affect even healthy reef systems, the chances of recovery after such damage are higher on reefs that are not stressed by other factors. A healthy ecosystem is simply more resilient to climate change than one that is already stressed.

12. Are there things we can do, in addition to limiting greenhouse gas emissions, in management of these resources that will make them more resilient?

Yes. Many of our natural ecosystems experience multiple stressors. Removing those stresses that we can control lessens the total stress on an ecosystem and increases its resilience to the less-controllable stresses associated with climate change. Management strategies to reduce stresses on our coastal ecosystems will vary considerably from region to region, depending on types and severities of the stresses, as well as social and economic issues.

Ms. BORDALLO [presiding]. Thank you very much, Dr. Kleypas.

The Chairwoman now recognizes Dr. Sharp to testify for five minutes.

[17] Kleypas, JA and CM Eakin (2007) Scientists' perception of threats to coral reefs: results of a survey of coral reef researchers, Bulletin of Marine Science 80: 419-436.

STATEMENT OF GARY SHARP, Ph.D., SCIENTIFIC DIRECTOR, CENTER FOR CLIMATE/OCEAN RESOURCES STUDY

Dr. SHARP. Thank you very much for inviting me. I hope that we can answer lots of your questions about different time scales, the different places on the planet where things are definitely going differently.

Ms. BORDALLO. Sir, would you move up just a little closer so we can hear you better? There you go.

Dr. SHARP. There is a clear record, yes indeed, that global warming has occurred. There is no question I think in any person who is an empiricist, and I claim to be an empiricist.

The important thing is the changes since 1860 are those only for which we have real numerical measurements, observations and that sort of thing, so we have essentially 147 years of information we can put on a chart someplace and talk about degrees Fahrenheit or degrees Centigrade, depending on how fuzzy you want to get.

The bad news is most of those measuring tools even today are not calibrated well, they are not intercalibrated well, and the technology changes all too frequently making for a very messy set of records.

We do know that the major greenhouse gas by definition on our planet is actually a water vapor in the form of clouds and/or moisture in the atmosphere. We also know that since 1860 we have had a very nonlinear set of weather changes all over the world, and in fact if you do the averages and find numbers, from 1860 until about 1915 not much happened even though we were coming out of the Little Ice Age for quite a while.

Between 1915 and 1945, temperature rose essentially .4 degrees Centigrade, a little less than half a degree. The period between 1945 and 1965 the temperature dropped again. Meanwhile, CO_2 is still kind of climbing along so there has to be some kind of a little bit of a problem trying to relate A to B to Z in that particular case.

Around 1967 or so we began to see all sorts of changes in the coastal oceans, the most productive places in the oceans, because the updwelling communities were actually slowing down. The recruitment was going down. The animals who lived offshore in the warmer water were moving onshore and recolonizing coastlines.

In this case what we are really seeing is in 1976 with the intensification of the El Niño frequencies and other things we saw general northern hemisphere ocean warming that takes 10 to 15 years to work its way toward the poles in both directions. Every time there is an El Niño you see these long-term processes going on.

We keep seeing the pretty little movies of the thing running up and down the coastline, the waves and that sort of thing. That is the short-term phenomenon. The long-term phenomenon are the waves that bounce off the coastlines and finally take eight to 10 years to get into the Bering Sea from the warm pool or around the corner into the South Atlantic and dissipated around the South Pole.

Now, those processes are not built into these wonderful global climate models. That is a real frustration for those of us who are empiricists and have worked in this field for a long time.

The other problem that I have made fairly clear here is that the human contribution to all greenhouses gases is less than .3 percent, .03 percent. You try to find that on your thermometer. It is very, very complicated to try to blame human contributions in that sense.

What we do know is that there is an awful lot of information in the sciences that shows that the major phenomena caused by people are related to urbanization and land use changes, and one of the rules of society is when it warms humans swarm. In that same 150 year period, 157 years, we went from one billion to 6.7 billion. It took an awful long time to get to that one billion, and we lost an awful lot of people every time it cooled down.

I run a continuous, as I say, recording of these things on my website. It is called It Is All About Time, and it has a chronology essentially of the warming and cooling phenomena for the last 4.6 billion years and their consequences in population, the human population, and ecological systems.

When you look at that, warming has never been bad for humanity in the same sense that cooling is. Cooling in this sense can be a few decades or a major cooling event. Every winter we lose more people. Your obituary columns climb like crazy starting in November compared to the summer and the heat waves and all the rest of the stuff that goes with it. Pay very close attention to those little facts.

The bottom line is I have been working in the international community for a long time. The Russian science, other things that are going on out there, we have wonderful ways of projecting what is going to go on in the marine environments. We have very clear records from old, long-time series that this has all happened before.

There is nothing new going on right now, but there is definitely a trend that is really difficult to deal with, and that is the number of mouths we have to feed for the rest of our lives.

When we think about that, I wrote a book a few years ago with some colleagues, a master fisherman and a social scientist. It is called Out of Fishermen's Hands. I self-published it so I wouldn't get in trouble with anybody. It is essentially a historical description of how human beings moved off into the oceans and around the world and how all of that came to pass.

Our real problem is we cannot manage them because we don't have the observing systems left, the monitoring systems left, because all that money has been spent on modeling for equilibrium theory, and that has been a complete throwaway and resulted in disasters in fisheries management.

Two weeks ago I finished the English editing of the translation of the book in Russian by my colleague that I backed into in 1998 that actually has forecasts and projections for most of the major fisheries in the world and where they are going and why they are going that way.

We have a good, clear record that there is a 60-year cycle of coming and going of the major fisheries in the world, all around the world, and they have a certain amount of correlation or harmony. We are now in a null period. We are coming past the warm. We are actually seeing the cooling process happening. That is a major

management issue, and that is what I have been working on for the last 25 or 30 years.

Thank you.

[The prepared statement of Dr. Sharp follows:]

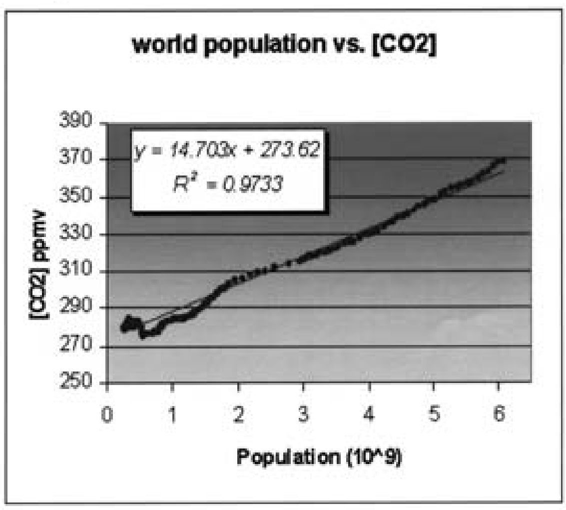
Statement of Gary D. Sharp. PhD, Scientific Director, Center for Climate/Ocean Resources Study, Salinas, California

What do we know about Climate Change, The Future and Humanity?

We know for certain only two things. The first is a matter of history rather more than science: namely, that since about 1860, when accurate temperature records were first collected on a comprehensive basis, northern hemisphere temperatures have risen by about 0.6°C; and that this coincides with a steady growth in the amount of carbon dioxide in the atmosphere, a proportion of which is a consequence of industrial and other man-made emissions.

The second is that our planet is kept from being too cold for life as we know it to survive by the so-called greenhouse effect, which traps some of the heat from the sun's rays. This is overwhelmingly—somewhere between 75 and 95 per cent—caused by clouds and other forms of water vapor; and the carbon dioxide in the atmosphere accounts for much of the remainder. But so great is the uncertainty of climate science that it is impossible to say—and it is hotly disputed—how much of the modest warming that has been experienced since 1860 is due to the man-made increase in carbon dioxide.

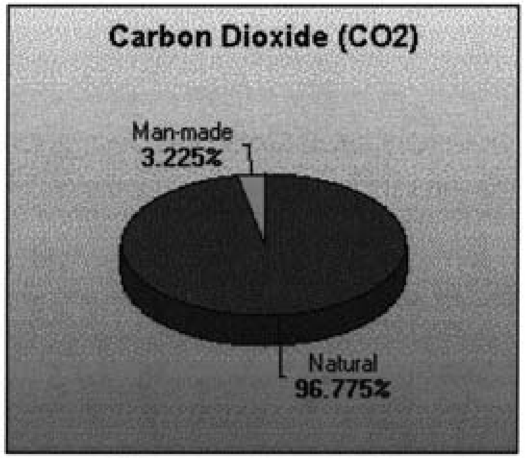
We also have some opinions that CO_2 levels and Humanity are related——



What is poorly recognized is that Global Warming since the Little Ice Age period of extreme low temperatures promoted the growth of both human population—and CO_2 levels—as will be shown.

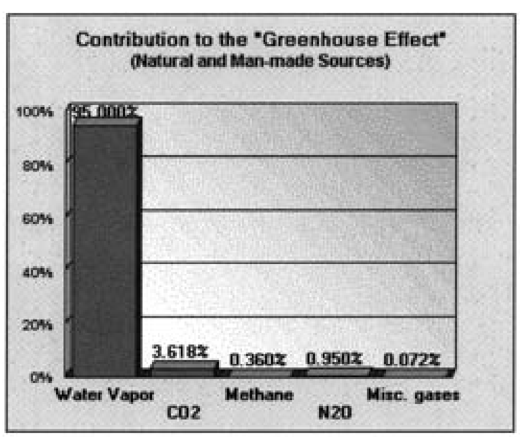
During the period since 1860, for which we have accurate temperature records, the picture is complicated. While the amount of man-made carbon dioxide in the atmosphere has, since the industrial revolution, steadily increased, the corresponding temperature record is more cyclical, displaying four distinct phases: 1) Between 1860 and 1915 there was virtually no change in northern hemisphere temperatures; 2) between 1915 and 1945 there was a rise of about 0.4°C; 3) Between 1945 and 1965 the temperature fell by about 0.2°C—and alarmist articles by various folks began to appear, warning about the prospect of a new ice age; and 4) between 1965 and 2000 there was a further increase of about 0.4°C, thus arriving at the overall increase of 0.6°C over the 20th century. Although, so far this century, there has been nothing to match the high temperature recorded in 1998, it would be rash to assume that this latest upward phase has ended. We know, however, that CO_2 will continue to rise—as human activities and their survival in general are still growing:

However, the human CO_2 emissions remain a rather small component within the Global CO_2 Cycle.

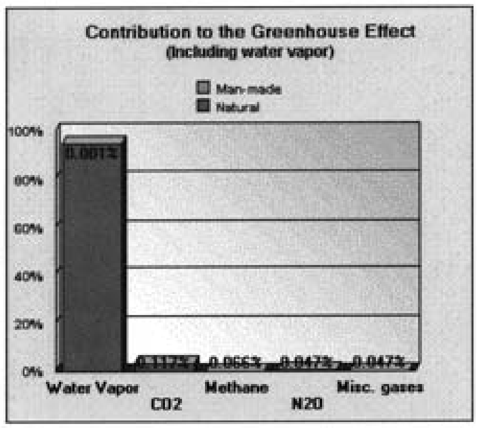


The IPCC Global Climate Change models assume that the recorded warming during the 20th century was entirely caused by man-made emissions of greenhouse gases, of which carbon dioxide is clearly the most important. This may be true; but equally it may not be. There are, for example, climate scientists who believe that the principal cause has been land-use changes, in particular urbanization (the so-called Urban Heat Island effect—as per Addendum 1—a note by James Goodridge, retired California State Climatologist—who has been collating the State Observations since the early 1950s), and to some extent forest clearance for farming. But much more important is the fact that the Earth's climate has always been subject to natural variation, nothing to do with man's activities. Again, climate scientists differ about the causes of this, although most agree that variations in solar influences play a key part.

What is too often "buried" is the fact that water vapor, the dominant component of the Earth's heat balance/transfer system, is affected by may variables, including the surface wind speed, Equatorial Deep Convection processes, linked to the higher latitudes via the atmospheric Hadley Circulation and related precipitation cycles, and the Earth's rotation—which along with the vast complex of ocean circulation dynamics comprise the timetables of Earth's Energy Balance System, little or none of which is under any specific control by humans, other than at very local scales, e.g. urban/farm environments.



Human contributions to the Total “Greenhouse Effectors” are quite small.



Total Human contribution to Green House effect = ~0.278% - not very great portion.

Needless to say, these confusing issues are likely to enhance future problems, if not dealt with correctly, and the more appropriate empirically based science rather than over-parameterized modeling continued. In my own rather complex field of Applied Fisheries Oceanography—we have suffered a rather odd parallelism with Climate Change Science—as modeling has taken over empirical observation based approaches to forecasts—and has resulted in many poor management decisions.

In February 2006, at the ASLO/AGU/CLIOTOP meetings in Hawaii I presented a lecture entitled - A Brief History of Applied Fisheries Oceanography - Part II - The Role Of CLIOTOP and TOPP in Revitalizing Ocean Sciences: In Short: “Underlying the basic responsibilities of resource management are very important questions requiring careful study, and long-term monitoring efforts in order to validate and upgrade conventional methodologies. While Ecosystem Modeling has become an academic field of general interest, the empirical observations necessary to build and implement effective models are rarely available, creating many examples of unreliable and unverified model results, that too often simply do not represent anything of real utility. E.G., Models that don’t reflect environmental contextual changes, directly, such as changes in thermal habitats, related production patterns, and direct species responses to well described known forces, other than simplistic Top-Down Trophic Energy Transfers, cannot reliably provide the needed insights necessary to either explain past changes, or project potential future changes. The last half century of poorly applied ’equilibrium-based’ theories, and collapse of most or all the important contextual variables into a single ’parameter’—often held constant—has resulted in the chaos that we see everywhere in stock assessments, management decisions, and resource collapses. A summary of historical efforts to move beyond ‘context-free’ management paradigms is provided. These many efforts have undergone several ‘bloom-and-bust’ cycles as generational changes in applied theory, and thus funding focus have been legislated over the years. The strong recent efforts to get back onto the oceans, working with knowledgeable commercial folks, and creating new technologies and better data sets from archival tags deployed on the various species has revolutionized ecological science, in general, but has yet to be integrated into the management procedures, or ocean science, in general. This is the future of applied fisheries oceanography.”

In fact, I have been working on trying to resolve this problem by working with other on the issues in-situ in the eastern Pacific high seas fisheries since 1967, and then expanded westward into the southern Pacific, and then globally, since the late 1970s. I worked closely with those individuals who had the capabilities to both map observational data, and create time series from which insights could be gained. I then applied my own experience in working with upper ocean thermal and O2 profiles in explanations of changes in animal behavior and the changes in vulnerability of a broad array of ocean species to various fishing gear types, and helped those in developing regions “optimize” their yield per unit effort, and minimize both their energy usage, and by-catch.

Eventually, on returning from my international efforts, to the USA in 1983—I discovered that our ocean observation programs were amongst the most devastated and poorly supported of the many fishing nations I had been working with. On the other hand, there were many related fields of science, from paleoclimatology to coping with regional weather that were well studied, and insights were shared routinely at various annual conferences, of which, I discovered the most eclectic (and often most irreverent) was the Pacific Climate Conferences held in Monterey Bay since 1984—where I was invited in 1986 and showed the NOAA archived film of the GOES-E and GOES-W satellite imagery of the entire sequence of processes related to the El Niño of 1982-83—starting with Pacific-wide coverage from January 1981—until march 1983. My major contribution to this eclectic group was that I ran the sequence "backward", after asking the audience to chose their particular locale of interests—and allowed them to track any features that affected these locations back to its source, usually well away from the locale—in fact, half a world, and months away from what they were interested in.

I soon found myself working closely with James D Goodridge, retired State Climatologist, on the source of the changes observed in the State of California, since records began in the later 1800s. Goodridge had learned about Anthropogenic Forcing of Urban Temperature Trends in California"—from decades of changes he observed, since he started this research in the early 1950s—and has been updating those records routinely since he retired in 1983. (A brief statement of his in addendum 1)

As we read both the news releases and "professional Journal" articles about the pending calamities related to Global Warming it is too often not made clear that these are merely hypotheses—not more than the results of computer calculations based on limited understanding of causalities, and modifiers on various time and space scales. One example, of many similar issues is the infamous Conveyor Belt dialog- which Carl Wunsch, of MIT, made very relevant statements about last year:

Correspondence Nature 428, 601 (2004) - Gulf Stream safe if wind blows and Earth turns

Quote - Sir - Your News story "Gulf Stream probed for early warnings of system failure" (Nature 427, 769 (2004)) discusses what the climate in the south of England would be like "without the Gulf Stream". Sadly, this phrase has been seen far too often, usually in newspapers concerned with the unlikely possibility of a new ice age in Britain triggered by the loss of the Gulf Stream.

European readers should be reassured that the Gulf Stream's existence is a consequence of the large-scale wind system over the North Atlantic Ocean, and of the nature of fluid motion on a rotating planet. The only way to produce an ocean circulation without a Gulf Stream is either to turn off the wind system, or to stop the Earth's rotation, or both.

Real questions exist about conceivable changes in the ocean circulation and its climate consequences. However, such discussions are not helped by hyperbole and alarmism. The occurrence of a climate state without the Gulf Stream any time soon—within tens of millions of years—has a probability of little more than zero.

Carl Wunsch - Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, Massachusetts 02139, USA"

And then—consider that many of us have been working on these issues for a long while, based on the early works of folk such as those trying to resolve the changes in marine ecosystems from the Baltic and Northeast Atlantic at the end of the 19th Century, E.G.

The first president of ICES - the International Council for the Exploration of the Sea—spent decades researching the relationship between weather and fisheries:

Pettersson, Otto, 1912, The connection between hydrographical and meteorological phenomena: Royal Meteorological Society Quarterly Journal, v. 38, p. 173-191.

Pettersson, Otto, 1914a, Climatic variations in historic and prehistoric time: Svenska Hydrogr. Biol. Komm., Skriften, No. 5, 26 p.

Pettersson, Otto, 1914b, On the occurrence of lunar periods in solar activity and the climate of the earth (sic). A study in geophysics and cosmic physics: Svenska Hydrogr. Biol. Komm., Skriften.

Pettersson, Otto, 1915, Long periodical (sic) variations of the tide-generating force: Conseil Permanente International pour l'Exploration de la Mer (Copenhagen), Pub. Circ. No. 65, p. 2-23.

Pettersson, Otto, 1930, The tidal force. A study in geophysics: Geografiska Annaler, v. 18, p. 261-322.

More recently reviewed by Julia Lajus—a Russian Social Scientist: http://www.meteohistory.org/2004polling_preprints/docs/abstracts/lajus_abstract.pdf

Influence of weather and climate on fisheries: overview of emergence, approval and perception of the idea, 1850 "1950s. Julia A. Lajus St. Petersburg Branch of the Institute for the History of Science and Technology, Russian Academy of Sciences, and Centre for Environmental and Technological History, European University at St. Petersburg

"Fishermen have long known that fisheries appear and disappear in time. Such events were attributed to changes in fish migration routes, harmful growth in numbers of natural predators of fish, and to the human impact: overfishing and water pollution (Smith, 1994, pp. 21-34). To note that weather, especially the changes in wind direction, could influence fisheries, was easier than to suppose that large periods of fish abundance could be connected with the fluctuation of climate. For example, Karl Ernst von Baer, famous German zoologist, who worked in Russia and in addition to many diverse activities was a head of several expeditions which surveyed the state of fisheries in 1850-s, explained the severe decline of herring fisheries during several years in the eastern part of the Baltic Sea by very cold and windy springs occurred these years. He supposed that the winds pushed out the spawning herring from their usual spawning grounds (Baer, 1860). But at the same time he did not apply this kind of argumentation when he discussed the possible causes for the cessation of the very prosperous herring fisheries in Bohuslan region on the western coast of Sweden in the beginning of the 19th c. He supposed instead that it was the human-induces pollution due to fish oil production. For the first time the climatic explanation for the periodicity of these fisheries was suggested by Axel Ljungman in Sweden (Ljungman, 1882). He noted that the herring catches varied cyclically with a period of the fifty-year sunspot cycle and assumed that this relationship might be explained with changes in the weather. However, he was not able to propose the mechanism for that connection.

When the International Council for the Exploration of the Sea (ICES) formed its Committees in 1902, they were named according to the main problems, which understanding would provide the better knowledge of the reasons of fluctuation of catches in fisheries—Migration Committee and Overfishing Committee. Hydrographical Committee was established in 1905. While the importance of studies of the environment for understanding the distribution of marine life was the core idea which led to the foundation of the ICES, during several decades the interdisciplinarity of research efforts was proposed but not fully achieved. According to T.R. Parsons this dichotomy continued through the 1960s: fisheries biology concentrated mostly on population dynamics, excluding the role of environment in controlling the absolute abundance of various fish species (Parsons, 1980). The exception was the situation in Russian marine studies where fishery science was merged with oceanography several decades earlier, forming the fisheries oceanography. Interest to the environmental forces was very much pronounced in Russian biology at the expense of the development of population modelling.

While it was "the struggle to link fish to their ocean environment" within the ICES (Rozwadowski, 2002, pp. 111 -145), to link fish with the climate was even more difficult task, as the relations between ocean and the atmosphere remained enigmatic. In 1910s Johannes Petersen from Denmark and Otto Pettersson from Sweden discovered connections between the water temperature in the North Atlantic and the position of the air pressure minimum (Icelandic low), but the nature of these connections were not obvious (Petersen, 1910, Pettersson, 1912).

However, already the first ten years of studies under ICES umbrella had resulted in the discovering of the unexpectedly high variability in the ocean. As it was pointed out in the ICES Memorandum in 1923: "We started from the assumption that the hydrographic conditions, as well as the fishlife and the plankton of these tributaries of the Atlantic, seemingly so well separated both from each others and from the main basin of the Ocean by narrow channels and submarine thresholds, would remain on the whole stationary, subject only to seasonal influences from the atmosphere. Experience has led us to other views. There exists an interchange of waters of living marine animals and plants between the different parts of the Ocean on a far greater scale than our most experienced oceanographers and biologists considered to be possible twenty years ago" (Pettersson, Drechsel, 1923). The notion of far greater scale of variation in both physical and biological phenomena than it was considered as real or even possible was a main tendency in the discovering the environmental forces driving living organisms in general. It was especially true for the climate, which was perceived as much more stable than it occurred to be. For example, Russian biologist and geographer Leo Berg in his book "Climate and life" (Berg, 1922) compared climate with a species and weather with an individual, arguing that weather is very changeable, while climate could changes only very slowly. The same was an opinion of Russian oceanographer Nikolai Knipowitsch who was the Russian delegate in ICES before the WWI. He considered the Gulf Stream system as a stable

one and thus was extremely surprised when the significant increase of the water temperature in the Gulf Stream branches in the Barents Sea was discovered in 1921 (Knipowitsch, 1921). In 1926 Otto Pettersson wrote a classical paper, in which he demonstrated very clearly the connections between catches of herring and winter temperatures in the Kattegat channel (Pettersson, 1926, see also Svansson, 1999).

The significant warming in the North Atlantic which started in the 1920s and was more pronounced in the 1930s provided many new evidences of the influence of climate on fish distribution. The effect was especially visible at the north-west—in the Greenlandic waters and at the north-east—in the Barents Sea. A.S. Jensen and P. M. Hansen (1931) observed the expansion of cod and halibut along the west coast of Greenland in comparison with 1908 and the 1920s. The warming of the Barents Sea also was accompanied by the large changes in the distribution of stocks of commercial fishes. The tremendous amount of herring never seen before near the Russian coasts of the Barents Sea was observed in 1932-34. Herring was observed even in the mouths of large Siberian rivers (Esipov, 1938; Galkin, 1940). In the same years cod appeared in the quantities suitable for fisheries at the eastern parts of the sea and even near the Novaya Zemlia costs (Esipov, 1935). Thus "warming of the Arctic", which was noticed firstly by climatologists and oceanographers became an important issue for biologists. In Russia it was summarized in 1934 by Sergei Averintsev (Averintsev, 1934) for the Barents Sea and more generally by Leo Berg (1935).

The perception of the rapid climatic changes and their influences on fish resources was rather contradictory. Most of the scientists considered this as the random event, others tried to discuss this in terms of the periodicity. Both considerations were very unfavorable for fishery managers who would like to have in hands the control sticks for the ruling of fish stocks while referring to the climatic factors moved them far away from this practical task. Contradiction between the supporters of the overfishing as a main factor influencing the fish stocks and scientists who believed more in the environmental forces was appeared very clear in the dispute between W. F. Thompson and Martin Burkenroad over the fate of the halibut stock in the Pacific (Smith, 1994, pp. 267-276).

The marginal but interesting example came from the Soviet history: in 1930s it was a period when managers and authorities opposed the very idea of influence of climatic changes upon fish stocks, because it put serious limitations to the will of reconstruction of nature by the human voluntary. The paper by Averintsev mentioned above became a point of severe criticism, because the linkage between the warming of the Arctic and the increasing of the catches of herring and cod led to the assumption that when the warming will stop or the cooling will start (the climate is so uncertain and mysterious thing!) the catches undoubtedly will reduce. This pessimistic view was not appropriate for the optimistic position of the conquerors of nature and for the planned Soviet economy.

Growing understanding of the importance of climate influence led to the organizing of special meeting on this subject in 1948 (ICES, 1948). H. W. Ahlmann in his introductory speech pointed out that extent of warming of the northern waters which was documented in 1930-1940s was part of a global change of larger scale pronounced by increasing of air temperature, receding glaciers, decreasing Arctic ice extent and thickness. From that time we could trace the formation of the interdisciplinary research program intended to the discovering of the mechanisms of the influences of climate changes on fish. The development of this research program which core was the assumption that the climate changes have significant influence on fish and fisheries was smoothed by the describing of several important phenomena such as the Great Salinity Anomaly, North Atlantic Oscillation and El Nino, which were connected with the dynamics of the fish populations (Drinkwater, 2000).

After summarizing book by D. H. Cushing (1982) the notion that climate change could influence the fish resources and therefore fisheries became a commonplace, but the question is still very important and new facts and correlations are discussing by fishery scientists in cooperation with climatologists (Cod and Climate Change, 1994 and many others). The real issue is whether there is a direct causal link, or these are merely correlated consequences of larger scale processes (Sharp, 2003).

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Meanwhile, back in 1987 I wrote the following essay:

Averaging the Way to Inadequate Information in a Varying World

"At the Benguela 86 Symposium one of the participants decided to make a very strange recantation. There was sufficient evidence, in his view, to suggest that there

was no reason to do the causal research in fisheries-related marine ecology, once the conventional average fishery information or parameter estimates were available. You could be right more often using average expectations in your data than if you used any three random variables with combined explanatory capabilities of up to 75%. He then proceeded to exemplify his conclusions from his analyses.

This statement came as a surprise—and disappointment—as it came from an exceptionally talented mathematical analyst. Perhaps doubly so, since among the several dozen other presentations at this symposium there were also very memorable contributions that evidenced the value of understanding the causal sequences of climatic to, oceanographic, to ecological events and patterns, that characterize the dynamic Benguela Current Ecosystem, in particular its periodic reversion from one quasi-stable state to another.

I suspect that, once stated, such a position will make it more difficult to induce such "enlightened" folk to recognize the logical errors that lead to these wrong conclusions. As Jorge Csirke and I concluded after our 1983 review of the Changes in Abundance and Species' Composition of Neritic Fish Resources, fisheries stock assessment would be in a very different state if the North Sea were subject to El Niño events.

In retrospect, I think that any argument for use of simple averages is a strong signal that it is about time for such analysts to be removed to the back seat, or somewhere that will minimize data fatigue. Recent decades have been the hey day for the near-miss regression/correlation approach to modeling environmental affects on resources populations. There is a subtle philosophical twist attendant to the failure of these partial models to forecast ad infinitum the patterns of any populations responses to regimes outside the models' basis, of reference period.

There is no reason to expect that the low-level modeling that we have accomplished could forecast any but past responses—That is 'if' the signals were strong enough to make projections from. Yet, we assume average responses without querying the potential for any other dominant variables to emerge."

The most important relevant realization that needs to be made is the following:

THE AVERAGE FISH DIES WITHIN ITS FIRST WEEK OF LIFE!

And - Where does this leave our mathematician? With a lot of surviving, not-so-average fish. In fact the average conditions of the ocean will not support most fish life at all. Therefore, there must be some alternative way to organize the science if we are ever to reach the objective of forecasting even the less subtle aspects of marine populations such as relative abundance or distribution. I think that the solution is for fisheries researchers to go back to the basic questions of elementary biology. What mechanisms do the various populations have, and at what developmental stages, that allow them to survive local environmental perturbations? What are the conditions to which these individuals are adapted, and finally, what perturbs these conditions in time and space?

We should no longer attribute meaning to the word "average" in the context of any marine population. There should be a sense of the basic fitness of individuals on local time and space scales, not of a median: or population mean. In the context of marine environments, there is neither a mean expectation, nor a sequence of biological responses that have proven to be inviolable. Once we throw away our averaged or Atlas concepts we can experience dynamic changes, be they merely subtle diel processes, lunar responses, onward to greater time and energy scales.

Any given time period as short as man's expected lifetime or less may not offer as great a spectrum of perturbations and responses as have been experienced by a particular population or ecosystem, particularly climate regimes. For example, the general heating trend that has been experienced in the eastern Pacific Ocean since the late 1960's, which culminated with the 1982-83 El Niño, not only returned the physical environment to a previous "normal" state for the epoch that ended some 5,000 years ago, but many species that had somehow managed to retain "footholds" within the more recent habitat, that thrived in the other warmer state, bloomed, and replaced the more recent faunas for a short period. Where is the utility of the average concept in this context?

Progress over the last two decades toward an integrated, ecologically based fisheries monitoring and management regime has resulted from the near kaleidoscopic variability of the marine environment in response to usual decadal and epochal scale climate variabilities—global and local phenomena that could not be ignored.

Why has our mathematician given in? In the Benguela Current, recorded exploitation patterns of the fisheries have provided only short and incomplete information about these cyclic and aperiodic processes. The stability of the anchovy production since the collapse of the sardine population in that system may be completely artifactual, yet it lulls those interested only in the analyses of fisheries production

into a sense of security which is likely to be short-lived. While it is plausible that averages could provide adequate protection in a system which experiences only subtle perturbations, I doubt that the Benguela or any other Eastern Boundary Current would qualify.

Fisheries management should be about tesselations; careful analysis of not only man's harvests, but also the causal physical-climatic-oceanic processes, near and remote, that initiate ecological perturbations.

Emanating from this cascade of physical and biological signals are the unique experiences of surviving individuals, not the deadly averages. For Example: Addendum 2—my article in 1981 ICES Report, 178:158-160. COLONIZATION IN FISHES—SOME INFERENCES CONCERNING REQUIREMENTS AND OPPORTUNISM IN THE SEA "

Twenty years later I encountered the works of Leonid Klyashtorin, and had him introduced to my colleagues at FAO Fisheries Department in Rome. He was invited to come and present his work, and then asked to write a Technical Report—for which I was asked to do the final English editing for publication, Klyashtorin L.B. 2001.Climate change and long-term fluctuations of commercial catches: the possibility of forecasting. FAO Fisheries Technical Report No.410, 98pp. FAO of the United Nations, Rome. which is available online via this link:

http://www.fao.org/DOCREP/005/Y2787E/y2787e01.htm#TopOfPage

I followed up on this work, and my collaborations with Joseph Fletcher and others, and wrote another technical report - "Future climate change and regional fisheries: a collaborative analysis"—available from FAO Library via this link:

<ftp://ftp.fao.org/docrep/fao/006/y5028e/y5028e00.pdf>

In which you can read my views on the consequences of future climate change on regional fisheries around the globe.

I have just finished editing the English translation of Leonid Klyashtorin and Alexey Lyubushin's 2005 Russian language 234 page book on "Cyclic Climate Changes and Fish Productivity"—a long overdue re-introduction to the means for coping with the comings and goings of major fisheries populations. It will be available soon from the VNIRO Publisher in Moscow.

There are far more relevant bits and pieces of historical phenomena and observation-based research on library shelves in non-English language cultures than has been appreciated by many western scientists—and these need to be brought into the light so that western science might "catch up"—and move forward. More observations are needed and should receive priority over wasteful modeling ventures "

Enough said.

Addendum 1

On Global Warming
A California Perspective

BY JIM GOODRIDGE—CALIFORNIA STATE CLIMATOLOGIST (RETIRED)

CLIPS FROM PRESENTATIONS MADE IN 8/2006

There are two schools of thought on Global Warming. One is based on the concept attributed to Richard Feynman "Shut Up and Calculate". This is the concept was apparently used by Jim Hansen et al of NASA. He and others, who would average all the temperature records together, praying that the rising trends would average out the declining trends and yield a true idea of the actual long term trends. This reflects the consensus of the Intergovernmental Panel on Climate Change: that global temperatures are increasing due to anthropomorphic causes. In the words of Sam Harris "While consensus among like minds may be the final arbiter of truth, it cannot constitute it."

Another school of thought is to look at each temperature record individually and consider the influences that are acting on each record separately. When the trend is strongly upward, the influence of land use changes in the area of the measurement station needs to be considered.

About half of California's temperature records are from urban areas. They show a strong rising trend. The rural records show a nearly flat or no increase. The neutral trend in the rural areas is completely overwhelmed by the massive upward increase of the urban temperature trend. When the urban and rural records are averaged together the grossly distorted urban trends prevail.

About half of California's temperature records are from urban areas. They show a strong rising trend. The rural records show a nearly flat or no increase. The neutral trend in the rural areas is completely overwhelmed by the massive upward increase of the urban temperature trend. When the urban and rural records are aver-

aged together the grossly distorted urban trends prevail. There are vast areas with no temperature records.

Needless to say the areas around the urban temperature measuring stations have experienced severe land use modifications during the period of temperature measurement. This corresponds to the period of unprecedented population growth. These land use changes translate to increasing amounts of heat storage in pavement and in heated buildings. These changes result in large amounts of the recent thermal pollution the temperature records with respect to the early part of those same records.

The urban heat island affect was extensively described by Helmut Landsberg in his book The Urban Climate. The urban heat island is caused by urban waste heat and land use modification. This reflects solar heat storage in pavement and concrete for release during the night, added to radiation from urban waste heat sources.

The large increasing mean daily temperatures in urban areas are driven by the sharply rising trend in the minimum daily temperatures. This is in response to nightly release of heat stored in pavement and concrete. Maximum daily temperatures do not reflect the same rising trends.

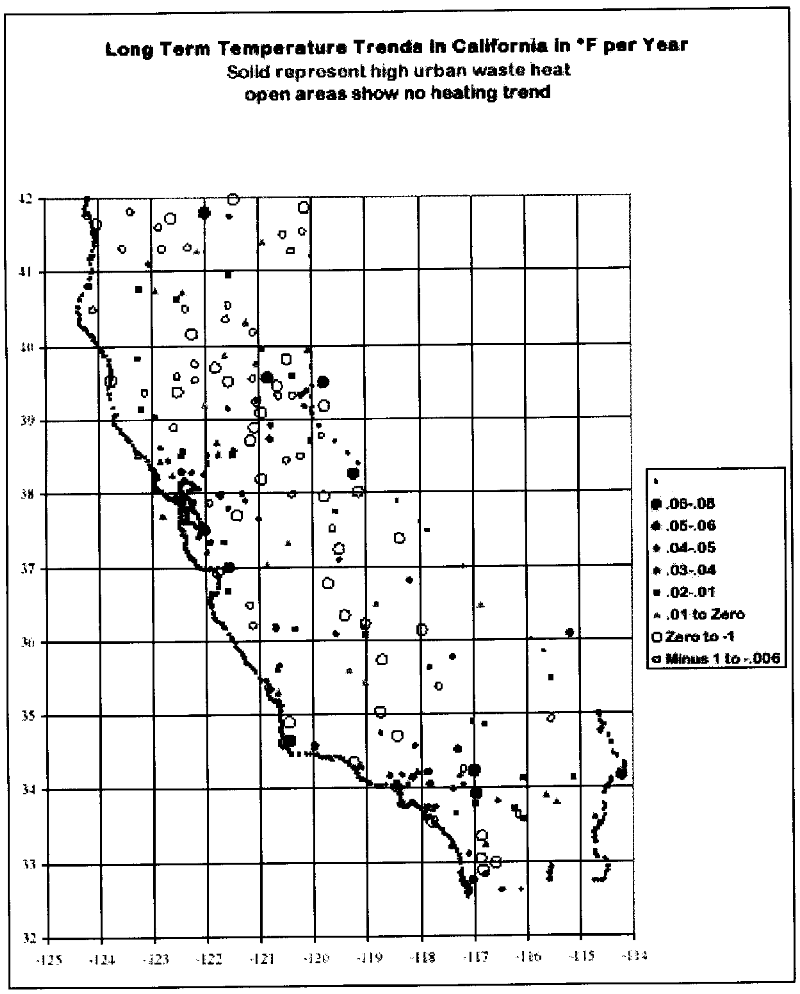
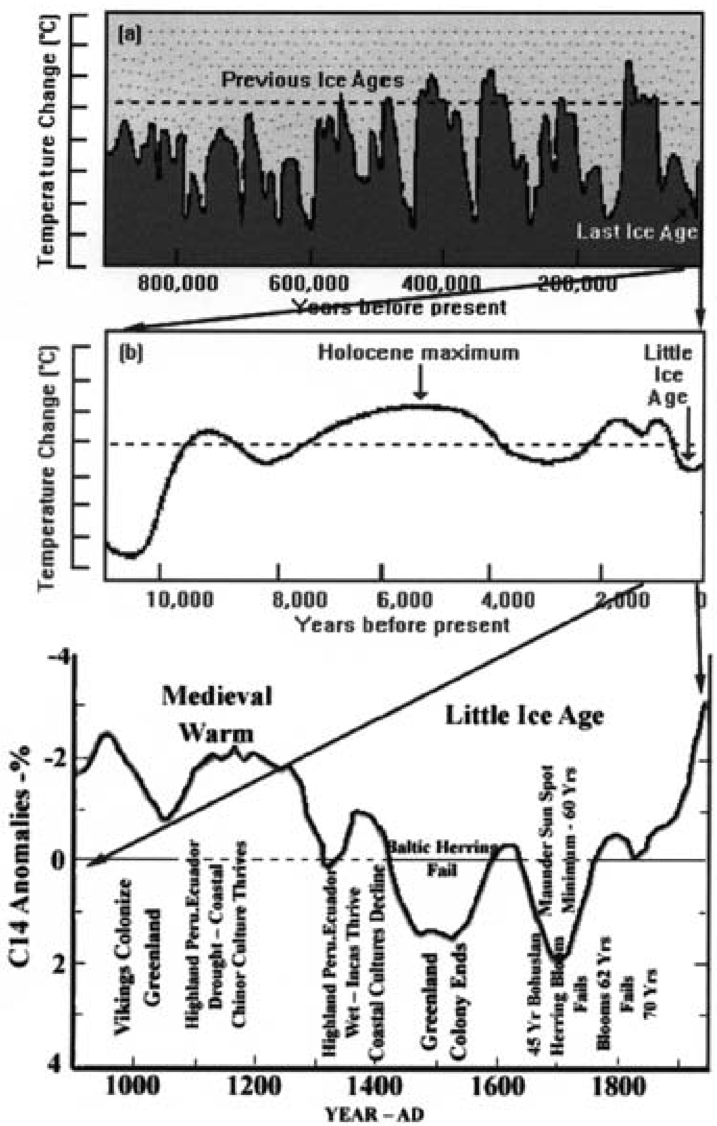


Figure 3: Long Term Temperature Trends in California in deg F per year

From a solar viewpoint the energy output of the sun or "Solar Constant" has been found to vary directly as the historic sunspot numbers. These were at lowest values of the recent millennium during the period from 1660 to 1710. This was the time of the Maunder Minimum of sunspot activity, with few or no sunspots. This also corresponded to the time when England's River Thames froze over. The ice supported a series of Ice Fairs mid river, just up stream from London Bridge.

The period 1300 to 1850 is referred to as the Little Ice Age. It was preceded by a warm period when Greenland was colonized over a thousand years ago. Earth's temperatures are still recovering from the cold times of the Little Ice Age, hence the retreating glaciers.



(Figure above from Sharp presentations)

Anthropomorphic global warming remains one of the "lies that bind" us to distorted view of a causal mechanism. To follow Feynman's suggested "Shut Up and Calculate" is to ignore the flaw of averages. Anthropomorphic global warming concept was "formed with inadequate evidence and can therefore be rejected with inadequate evidence" to again paraphrase Sam Harris.

There is a basic dishonesty using the concept of anthropomorphic global warming to justify conservation of natural resources. The conservation of natural resources is still an important and noble aim. The unprecedented numbers of the human population has inflicted an unprecedented demand on the natural resources as they are consumed for food, fiber, fuel and shelter. This human population explosion is inflicting unprecedented havoc on much of the natural area of California and of our planet.

List of State High and Low temperatures:

http://en.wikipedia.org/wiki/
List_of_all_time_high_and_low_temperatures_by_state

Theodore Landscheidt (d2006) final (correct) ENSO Prediction for 2006-2007:

http://www.john-daly.com/theodor/new-enso.htm

Website—Its All About Time - A Chronology of Events, Places, Ecological and Societal Impacts

< http://sharpgary.org/>

Addendum 2

Rapp. P.-v. Wen. Cons. int. Explor. Mer, 178:158-160. COLONIZATION IN FISHES - SOME INFERENCES CONCERNING REQUIREMENTS AND OPPORTUNISM IN THE SEA—Gary D. Sharp, FAO, Fishery Resources and Environment Division, Via delle Terme di Caracalla, 00100 Rome, Italy

Some of the least considered topics in fisheries research have been the initial colonizations and range extensions of species. The significance of these processes is obvious in proliferation of subspecies, and speciation and population cycles in fishes. All aspects have been treated, but a full appreciation of the spectrum of possibilities has yet to be made. The cosmopolitan species represent one extreme situation. A fundamental requirement is that there be a high degree of nomadism, with cohesion and sexual parity (similar stages of development) in the various nomadic elements (schools or shoals). The data providing insight into this process in cosmopolite species is the high degree of kinship in genetic sampling of highly mobile oceanic species (two species of tunas) (Sharp, 1978). For proliferation of the oceanic scale there must also be continuous "search and sample" processes in which the reproductive success rate is relatively high. Location of appropriate patches for larval development in oceanic species, particularly the cosmopolites, must be exemplary of opportunism in the most stringent sense. Many of the cosmopolitan species are not very long-lived, and their reproductive behaviour is relatively "cryptic". Their reproductive behaviour is different from the most discussed pelagic groups, the clupeids and engraulids, which are typically harvested most intensely during or just prior to their reproductive period due to their strong shoaling behaviour during this time. Localization of these reproductive aggregations is indicative of the tendency for these species to home on geographic phenomena which have historically provided them with successful conditions for reproduction. These conditions are just recently being subjected to vigorous examination required for determination of cause and effect relationships (Vlymen, 1977; Beyer and Laurence, this volume; Owen, this volume).

Resident or homing subspecies, races, or behavioural components in contrast to nomadic opportunists can be observed on all scales. In the California Current system, the anchovy and the sardine before its decline have been shown to have at least three geographic racial components with significant overlap between any contingent pair of genetic units (Vrooman and Smith, 1971). There is extreme racial complexity in the less mobile of the tropical tunas (e.g., yellowfin tuna in the eastern Pacific Ocean) and ocean scale population complexity of the more migratory cosmopolites such as skipjack tuna (Sharp, in preparation, Fujino, 1970). There are numerous indications of similar processes in the North Atlantic pelagics. Recolonization of fishing grounds where commercial quantities of one species or another have diminished to nil is exemplified by the Japanese sardine which has begun a slow march from its last bastion in the eastern pelagic zone of Japan to the Sea of Japan around the southern tip of Japan, nearly back to the historic range of distribution during the peak years of its exploitation (Kondo, 1978). This long slow march is characteristic of fishes with limited nomadic tendencies and exemplifies the relatively slow procession of colonization by such species in contrast to the more migratory oceanic species and forms.

The qualities of habitat which determine the population distribution are entirely distinct from those which truly determine recruitment. The larval habitat clearly has a more complex series of constraints, on smaller scales and geometries, than the adult or more mobile stages. The limited mobility, small size, and relative sensitivity of fish larvae to micro scale parameters places them in jeopardy at all stages. The homing species invest considerable energy in placing their eggs into the home habitat. If this home habitat has shifted or ceased to be appropriate for larval survival there is no hope for reproduction. Where the population habitat boundaries shift there is generally an effective reduction or increase in the potential larval habitat which directly influences reproduction success and realization of potential. Where the adult population habitat is shrinking one would predict a decrease in realization of reproductive potential. Where the adult habitat is expanding, if the adult population is not relatively nomadic, there is a tendency to under-utilize the larval habitat potential, yielding slower population growth than one could expect. In non-nomadic species, active transport by currents, wind stress field effects, diffusion, and sheer chance ultimately determines their rates of increase in both numbers and area.

Intermediate to these cases are species whose reproduction is not localized per se, but tends to be concentrated geographically due to the requirements of the larvae, whereas the adults and juveniles may be quite diffusely distributed and/or highly migratory, resulting in very different distributions at different life stages. In this situation species can even arrive at a "cosmopolitan" distribution.

If one concludes that the egg to larval transformation period is the greatest potential "bottleneck" period for a fish population, then one can also conclude that the complexities of the following life stages represent an evolutionarily successful egg's way of getting itself reproduced and redeposited in an appropriate environment. The subtle generation to generation responses to environmental trends and anomalies selects for either geographic flexibility, as observed in the nomadic opportunists, or numerical swarming as observed in the clupeids and engraulids, which is restricted, for success, to areas of relative year to year stability. The rise and fall of these localized populations is probably more characteristic and dramatic than the year to year biomass or number variations in the opportunistic nomadic forms. For example Table I shows the relative abundance (catch) variations in 25 local or regional pelagic fisheries from the years 1970 to 1977. All these examples have varied by more than 5 times during this period. No oceanic fisheries exhibited this level of apparent abundance variation within this period, apart from a few cases where political or economic factors other than resource availability have affected the total landings (FAO, 1977).

Table 1. Trajectories of catch trends since 1970.

Species	Area	(A) Peak catch	(B) Low catch	Ratio A/B	
Caranx hippos	West Africa	28 221	1 036	27.	+
Orcynopsis unicolor	West Africa	2 600	100	26.	—
Trachurus capensis	Southwest Africa	690 164	62 300	11.	+
Trichiurus lepturus	Southwest Africa	28 545	3 800	7.5	+
Trachurus trecae	Southwest Africa	273 700	31 298	8.7	—
Sardinella spp.	Southwest Africa	142 200	20986	6.8	—+
Scomber japonicus	Peru	65 000	8 700	7.5	+
Scomber japonicus	Northeast Atlantic	39 000	6 262	6.2	—
Rastrelliger spp.	Eastern Indian Ocean	16 300	2 000	9.2	+
Rastrelliger kanagurta	-Eastern Indian Ocean	203 100	35 403	5.7	—
Anchovies	Western Indian Ocean	118 062	16900	7.0	+
Psenopsis anomala	Northwest Pacific Ocean	13000	1 994	7.0	—
Sardinops melanosticta	-NW Pacific Ocean	1 420 512	16 900	84.	
Engraulis mordax	Eastern Pacific Ocean	289 002	44 600	6.4	+
Cetengraulis mysticetes	-East Tropical Pacific	168 081	15 551	10.8	+
Trachurus symmetricus	-Eastern Pacific Ocean	50 149	9400	5.3	+
Sarda chiliensis	Southeastern Pacific Ocean	74 700	4 341	17.2	—
Scomberomorus sierra	Peru	2 279	400	5.7	+
Engraulis ringens	Peru	13 059 900	907 175	16.	—
Sardinops sagas	Peru-Chile	1 467 555	68 600	21.	+
Trachurus trachurus	Peru-Chile	839 805	111 300	7.6	+
Thyrsitops lapidopodes	-Chile	7 200	630	11.6	—
Cetengraulis edentulous	-Venezuela	4965	850	5.8	—+
Decapterus russelli	Malaysia-Thailand	109 337	9 800	11.2	+
St Scomberoides spp.	-Indonesia-Philippines	5 186	500	10.	+

Plus and minus signs in the Table represent directions of trends during the reference period. Changes in both directions in the order indicated. The indication --+ implies sharp changes in both directions, in the order indicated.

The apparent relative stability of the biomass of the broad ranging opportunist populations is due to both contributions of local populations and the shared risks taken by the large nomadic portions of these populations in coursing over their ranges in search of feeding grounds and hospitable spawning habitats. The dependence of local populations of oviparous fish on the stability or continuity of local processes conducive to larval survival is well recognized. Our ability to identify many of the "critical" characteristics is developing. Until these characteristics are identified and monitored there is little hope that it will be possible to logically predict recruitment trends.

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Response to questions submitted for the record by Dr. Gary Sharp

QUESTIONS FROM THE HONORABLE PATRICK KENNEDY

Regardless of whether or not we take actions to control and reduce green house gas emissions, wildlife and wildlife habitat and the ocean environment are going to change and adapt, often unpredictably, to a warming climate. Consequently, we should take steps now to develop strategies to allow for the future conservation of biodiversity and the maintenance of a healthy and resilient environment.

1. Keeping in mind that any transition to a new "Green Economy" will take decades to achieve and that most Members of Congress will want to limit unnecessary disruptions of social and economic systems, can you be more specific on what practical types of adaptive management strategies we should consider to mitigate the negative effects of climate change on our collective wildlife and ocean resources?

Step One is all about re-establishing the efforts to develop an efficient and clean energy source. This issue has been dragged out of the public perspective for decades by selfish individuals and laboratory interests, as per the following history:

The concept of releasing fusion energy by igniting small pellets with intense beams of high energy heavy ions (HIF) was declared to have no fatal flaws in 1976. Comprehensive delegations from all the relevant USA laboratories with heads of laboratories, heads of the appropriate research programs, and Nobel Prize winners announced that the "brand X" laser that had been the object of an intense search for a technology that could "drive" inertial fusion power plants was in fact found in heavy ion beams. The systems to produce the ignition beams were feasible based on already demonstrated and understood technology. The existing Head of DOE's Office of Inertial Confinement Fusion, Dr. C. Martin Stickley, said in his summation

address to the Workshop on Heavy Ion Beam Fusion, the first of two decades of annual workshops, that the prospects for HIF warranted jump-starting the program with an initial facility in the $100million range.

No such funding ever materialized. While the positive facts of the technology were immutable, the negative facts of structural institutional differences were equally so. The laboratories conducting sub-nuclear particle research, and developing the required high energy particle accelerator technology, constituted a separate community from the laboratories whose historical mission was the development of nuclear weapons. HIF challenged the hegemony of the Lawrence Livermore, Los Alamos, and Sandia Laboratories over the program to achieve fusion energy by repetitive ignition of small fusion explosions.

While the Argonne and Brookhaven laboratories that had initiated HIF worked to define the technology path for the program and conducted demonstrations to validate key technological parameters involved in applying the technology of proton accelerators to accelerators of heavy ions, the DOE dragged its feet, and an untested accelerator concept promoted by the Lawrence Berkeley laboratory gained politically motivated adherents.

After three productive, albeit underfunded, years of the HIF program, a special committee led by Dr. Lee Teng of Fermilab was designated to vet the current accelerator-driver configurations at the Fourth Annual HIF Workshop in 1979. Teng's committee found that Berkeley's accelerator technology was high risk, as it had only been used to accelerate electrons, and noted that the HIF program had been systematically underfunded. Never the less, in the closing summation, Dr. Burton Richter declared that the Berkeley technology was the way to go. Contemporaneously with the 4th Workshop, the Authorization Committee in Congress was writing the death knell of the first effort at producing fusion energy from HIF. Regarding the DOE's budget for inertial fusion research, the Committee wrote "None of these monies shall be used for heavy ion fusion research."

A rump program continued with funding from the Office of High Energy and Nuclear Programs, but leadership of the program was transferred to Livermore and Los Alamos, neither of which had been contributing significantly to developing the HIF program plans. Livermore would oversee the Berkeley program and Los Alamos would oversee the Argonne and Brookhaven programs. The kernel that caused and justified the excitement about the HIF program was thrown away: the accomplishments of high energy particle accelerators were dismissed and the untested Berkeley concept would take the consolation prize funding to begin at square zero. Their endeavor would be to re-accomplish with a new technological approach what had already been accomplished from many decades of stellar accomplishments by the community descended from the pre-Manhattan Project founders of the modern physics enterprise. After 30 years, the diversion has proved to be the dead-end that was foreseen by most at the time.

The domestic HIF program was shattered, and the international community was dumbfounded. Where USA researchers had independent fiscal means, they continued to pursue the original HIF approaches, and worked with the international community, especially in Europe, until the permanence of the USA policy took its toll. Like the originators of the overall nuclear energy programs, the founders of HIF have aged and new generations are confused about the history of this program. But the report of the last effort by the European community in 1997 reiterated the consistent validation of the technology, and included the first thorough-going assessment of a basic concept added by Argonne in 1978 to increase the technological margins and reduce the cost.

Here the program sits. The fact of its feasibility cannot be changed. The need for fusion energy is increasingly clear. Unlike the concept of magnetically confined fusion, inertial confinement fusion offers solutions to the multiple materials problems associated with the high energy fusion neutrons. Heavy Ion Fusion capitalizes on all the advantages of the inertial confinement approach and the wealth of accelerator technologies to present the unimagined prospect for a timely solution to the world's energy dilemma. The technologies are even more ready now than they were in 1979. Heavy Ion Fusion is capable of a man-on-the-moon experience, as announced by President Kennedy: "Before this decade is out." This endeavor would be characteristically American, and once again give to the World a gift such as have made the USA the light of the World for the past century. This gift of the energy source for all time will be, factually, eternal. While the fundamental technologies are shared, USA leadership is essential. This is within our reach.

The premier contact person from which these facts and many contacts with the surviving "bright" generation of physicists can be further developed is Robert J. Burke—who lives in Santa Cruz, CA and e-mail address follows: (rjburke@earthlink.net)

The world has waited far too long for the solution to this primary issue.

2. Should we be doing more to re-evaluate our current policies for land use planning and public acquisition of land for wildlife habitat? Should we be adopting a broader landscape and ecosystem-based approach for protecting wildlife?

There are innumerable criteria that are needed if we are to make rational decisions about what lands/habitats that need greater protection and basic protection from human activities. These are only available/accessible from compilations of the various identified species that for whatever reasons warrant concern, and following up by learning which plant/animal species groups make up their diet, and which habitats provide these—given that all will be affected by climate changes on all time scales.

This all requires more empirical science, and careful ecosystem-based evaluations of likely scenarios—not mere lat-long block modeling, but 3-D real world scales and careful attention to local/regional historical weather patterns—drought, flooding, seasonality, etc. over as long a times series as possible.

All these issues were taken into account when Dr. Everett and I worked out the first NOAA Ecosystem-based Resource Management PDPs—submitted to Congress in 1988—and shelved as mere "funding enhancement efforts"—and still unacted upon—20 years later. The Report is available here: <http://sharpgary.org/EcoSys-BasedFMP.pdf>

On request, several of the Regional Fisheries Management Councils had created their own specific PDPs—all of which were buried upon entry of Bush I and his new appointees within NOAA NMFS.

3. Finally, how might such ideas be applied to the ocean and coastal environment and the wildlife therein?

There is no question that the "sensible approach" would entail re-thinking how the nation's natural resources: water resources, watersheds, and waterways are managed—as well as how to minimize conflicts and delays due to the vast numbers of competitive agencies, Environmental organizations and the public interests—not easy tasks. For example, today, in Central California—if there is a water quality issue—over twenty agency/institutional/public interest groups show up—claiming authority -delaying progress by years to decades, if anything really happens at all.

The California Wildlife protection Act has helped move things along—but the upland watershed scale issues remain in the quagmire of too many agencies etc that claim authority—and too few "problem solvers" to get things working.

In the more well managed oceanic regions, organizations have been charged with doing the job right—and these work based on unique efforts to cope with normal climate variabilities—inter-annual perturbations e.g., ENSO Warm/Cold Events, and all the associated comings and goings of resources—as well as the issues due to human extractions. The Eastern Pacific Tuna Fisheries have been under such management since the 1950s, and the western Indian ocean since the 1980s—both exhibit limited examples of overfishing—although there are clear examples of small regions within these large domains in which local practices that are not under the jurisdictions of the larger high seas management bodies have suffered depletions, etc.

Along the U.S. Atlantic coastlines and inland waterways—anywhere there are large human population there are distinct signs of habitat loss, pollution-related aquatic population consequences ranging from basic genetic perturbations to oxygen depletion events, and mass contamination with by-products from body lotions to birth control agents. These have been well described and poorly responded to—despite the efforts of NOAA's Milford Connecticut lab's studies of Long Island Sound since the 1950s, and multiple agency and institutional research along the east U.S. coast—and Chesapeake Bay in particular—for decades.

Along the west Coast, there are several sub-regional issues—starting with the Southern California Bight—which extends from about Point Conception southward into Baja California—a re-circulating marine environment that receives the rainwater runoff, industrial and sewage by-products from over 20 million people, creating a truly yucky environment for all associated marine organisms, and anyone foolish enough to catch and eat them. Then there are the "Events" that keep on happening such as the January 29, 1969, environmental oil-related nightmare in Santa Barbara, California—which I happened to fly over on my way to San Francisco—well Described here:<http://www.geog.ucsb.edu/jeff/sb__69oilspill/69oilspill__articles 2.html>

From Pt. Conception northward into the Monterey-Half Moon Bay region—there are far fewer people and industries to have major effects on the environment, except

for seasonal agricultural run-off—But from the north, flowing southward along the coastline from San Francisco Bay is a nearly steady stream of human pollutants and nitrogen over-loaded run-off that has direct consequences on some of the more coastal resources—Again, given California's geological history and the "natural" sources of both mercury and selenium—the question is not so much about human issues, but must also consider these and other "natural" potential toxins and their roles within the regional food webs.

California is hardly alone in these issues—but there are far more people directly exposed to the potential threats than most locations.

Despite the well meaning efforts of environmental groups, and their campaigns to "save" critical habitats such as tidal basins and wetlands, their understanding of the roles of wetland bacteria in the conversion of metallic mercury into methyl mercury—the real toxin—that affects all the higher trophic levels, and humans in particular, as we tend to prefer carnivorous fishes, that have concentrated these toxins... And we suffer.

As one proceeds northward along the west coast, into Alaska—we shift toward woodland environments—and except for the various populations associated with major river outlets and harbors—the aquatic environments are in reasonably good shape—plus or minus the occasional oil spills.

Alaska's coastlines are exceptional—as there are few really dirty or polluting industries, except for the worst cases of Oil pipeline leaks and just plain "disasters" as on March 24, 1989, the Exxon Valdez struck Bligh Reef in Prince William Sound, Alaska spilling 267,000 barrels of crude oil. The spill posed a severe threat to the valuable ecosystem of Prince William Sound and surrounding areas. Literally billions of dollars have been spent trying to clean up afterward, and monitor the consequences—but...

Meanwhile, the Hawaiian Islands (and all other sites of naval shipyards, present or past) are a morass of wreckage, pollutants and contaminated living resources. Given the local dependence upon marine resources for food, etc., one wonders how to improve things for future generations?

QUESTIONS FROM THE HONORABLE HENRY BROWN, MINORITY RANKING MEMBER

1. Do you or have you (or your organization) received any funding from the Pew Charitable Trust or the David and Lucille Packard Foundation? If so, please elaborate.

NO!

2. Are you currently a party to any law suit against the Department of the Interior or the Department of Commerce (or any of the agencies within these departments)? If so, please describe

NO!

QUESTIONS FROM THE HONORABLE WAYNE GILCHREST

1. If paleo-records show that corals existed in the past under high atmospheric CO_2 concentrations, why is it a problem now?

The question is of primary concern—and needs to be answered carefully, once the missing studies have been accomplished.

Most of Nature is subject to a phenomenon known as "HORMESIS"—or additive stress syndrome—which simply means that that most any living organisms that are subjected to more than one stressor—will exhibit distinctly unexpected but common responses—and despite thee not being any single "lethal" dose—eventually the additive consequences can/will result in the organism's death.

THE PHENOMENON WAS BEST STUDIED AND WELL DESCRIBED BY ARD STEBBINGS, OF THE UK INSTITUTE FOR MARINE ENVIRONMENTAL RESEARCH (IMER) IN PLYMOUTH, ENGLAND. He used a colonial hydroid species as an indicator/assay of environmental stressors—in the field, after years of laboratory study. The initial response of most organisms to low level stressors is an enhanced metabolism, faster growth and early maturation—a phenomenon that is well known and taken advantage of by egg farms (more eggs, earlier) and most livestock growout establishments (faster growth for less feed).

As I stated at my testimony—much of the coral bleaching observed occurs in regions where human effluents and other stressors are well documented—if only at sublethal levels—but add a few degrees F—and the symbiotic algal zooxanthellae—depart their coraline homes—and head for cooler, cleaner environments. The world's most complex reefs are found in the warmer regions—such as the Indo-Pacific Warm Pool—where water temperatures are highest—but are quite limited in that when they warm beyond 27.5C, they generate huge Deep Convection water vapor col-

umns—ejections of the warmest surface water into the upper atmosphere—creating the basis of the Hadley Circulation and general poleward transfer of heat energy and precipitation. These cloud cover formations reflect incoming IR and solar energy—maintaining a cooler upper ocean as the evapo-transpiration caused by the winds below continue to cool the upper ocean waters.

Why are the major coral structures found in these warm oceans?

All aspects of organismal physiology are accelerated—and for the micro-organisms that form coral structures, they are more efficient, and responsive. Remember that the majority of Australia's Great Barrier Reef is now situated over regions that were well above sea level only 20 thousand years ago- when humans walked from Asia onto Australian terrain. It is also arrayed over many tens of degrees latitude, from the equatorial region, southward into the subtropical latitudes—and if warming continues, will spread southward with its preferred water temperature.

2. Among the various effects of climate change to wildlife and the oceans, are there issues that are more pressing than the others?

Almost all the so-called "threatened" terrestrial wildlife are in direct competition for resources and habitat with humans, Species such as the polar bear and other predators are usually quite well adapted—and as such, have occupied their extreme environments since the warming began that ended the last Ice Age—Their prey are also moving out in front—as these changes occur—such that all their lower trophic level forage needs are the real source of their presences—in these extreme environments.

There is far more plasticity in these many species' pre-adaptations—selected over millennia—than we poor humans happen to share.

Removal of options, e.g. limiting access to waterways, shorelines, or open ocean access are the major concerns that I see need careful consideration, so that options remain that will help sustain all the players, not just one or another "cute" species.

Why?

We tend to over-value human interests—and forget that the majority of species that we are concerned with are dependent upon others—their supporting ecosystems and options for access.

3. In the U.S., as plant and animal species migrate north and to higher elevations, what does that mean for the regions they leave behind? For instance, it has been said that some U.S. states that border Canada might actually benefit from the next few decades of climate change, but what will it mean for the states further to the South, and especially those on the coast?

The expansion of species ranges northward has been ongoing for over 20 thousand years, as the last Ice Age ended and glacier coverage declined.

Every thing from migratory birds, fresh water fishes, and their predators took advantage of these changes—and what you see is what you get.

Literally thousands of rivers, streams, and ponds, lakes etc., are now inhabited—colonized by these well-adapted mobile species. Of course, don't forget that the forests and grasslands—even tumbleweeds—took advantage of the changes in options, as the ice disappeared, the wetlands and waterways emerged—and habitats expanded—then we had a few cold epochs—and humans that had also recolonized and prospered were back in competition for living space and resources—hence the European expansion westward and out onto the oceans—see my book, available via my website—"Out of Fishermen's Hands..." for a review of history of all these climate-related human issues. Nothing new going on today.

4. How do shifts in habitat range of plants and animals affect human interests such as agriculture or the spread of invasive species and diseases?

All available in history books—as per my note above...

How can we adaptively plan for such changes?

Don't assume "everything will stay the same"—if we do nothing.

That is the fallacy of the "Global Warming is Bad" mob—Humans have always been better off during Warm Epochs than Cold epochs—and if you pay attention to your local newspaper obituaries—you will note that there are far more deaths during the cool months than during the warm months—evening Europe over the recent decades.

Coping strategies should include careful development of more energy efficient transportation and power generations, with fewer pollutants—and toxins—of which

CO_2 is not a concern, as it is the basis of plant life and all primary production, on land and in the seas,

5. **The IPCC reports with 80% certainty that the changes in water temperatures, ice cover, salinity and ocean circulation are impacting the ranges and migration patterns of aquatic organisms. How will this affect management and use of these resources, and how can we prepare for any changes?**

Yawn! This is a misleading understatement—as all ocean species undergo routine and regular responses to the always changing environment—on all time and space scales. They have plenty of experience, and long-selected preadaptations to these changes—unless for one reason or another, their access to supportive habitat has been limited or removed, as per dams or filling in of habitat for other uses.

6. **In the Chesapeake Bay, we are losing marshland to rising sea levels. Can you talk about what is happening to coastal wetland areas in other areas of the country and what that is doing to their ecosystems and the local economies that depend upon these natural resources?**

Few if any regions are economically dependent upon their coastal wetlands—as these are by definition quite unstable, always dynamic environments. For those few locations that are experiencing rapid sea level rises—they were already nearing this status over a Century ago—as the total sea level rise has been about 10 inches per Century for Millennia—except in those regions where oil and gas removals and related continental subsidence are the main/dominant causes. Natural geological subsidence is also common, and yet, sea level rise is steady over the recent thousand or more years for the majority of the main continents—and will continue until the next Ice Age occurs—some millennia away.

Too many wild speculations about sea level rise are based on very unusual locations and their trends.

7. **What role do marshlands play in sequestering carbon? Is marsh restoration a viable alternative in carbon sequestration?**

Little or none, as these environments do not "store" biomass—and NO!

8. **The latest IPCC report warns that ocean acidification poses a threat to coral reefs and shell-forming organisms that form the base of the aquatic food chain. But the report says more study is needed to determine the full scope of the threat. What do we know about the potential impacts to U.S. coastal ecosystems today and how quickly is our understanding of acidification improving? What can Congress do to improve upon this understanding? Do we know enough to act?**

Again, What we know is based upon rather shaky data sets taken over the years, that used very different technologies—My main concern based on my own experience, is that the instrumental inter-calibrations that are necessary for a truly powerful scientific investigation have not been adequate to make any realistic statements about the relative contributions of anthropogenic CO_2 to pH changes that have been posted. A pH change of 0.015 over a decade is simply within the noise range of the pH measuring tools—In the Good Olde days—we calibrated the instruments aboard ship daily—but each pH meter had it's own "personality" thus the error range was greater than the numbers given above as "the recently observed changes".

9. **What additional resources or tools will the Fish and Wildlife Service and National Marine Fisheries Service need to adequately prepare and address the impacts of global warming on wildlife over the next decade?**

Lots of satellite archival tagging effort, along with in situ monitoring and calibration activities, as recently begun within NOAA & NASA working with the Census of Marine Life (CoML) Tagging of Pelagic Predator(TOPP) projects. Terrestrial projects are ongoing that compare well.

Both environments are being better monitored given these new technologies than ever—but the programs]need to be enhanced globally.

10. We've heard a lot about the polar bear and the petition to list the species under the Endangered Species Act (ESA). Opponents of listing claim that the effects of global warming are in fact unclear. What evidence is there that global warming is already having a dramatic effect on the species across its range? How will an ESA listing help polar bears?

This is an ENGO Scam—as the Canadian polar bear experts have already pointed out—and they have survived many such warmings over their species' history—and warming to a greater extent than today only 4-6 thousand years ago.

Ms. BORDALLO. Thank you. Thank you very much, Dr. Sharp.

The Chairwoman now recognizes Dr. Everett to testify for five minutes.

STATEMENT OF JOHN EVERETT, Ph.D., OCEAN ASSOCIATES, INC.

Dr. EVERETT. Thank you, Madam Chairwoman and Members of the committee.

My written statement presents the results of the work I led for the IPCC from 1988 to 2000. This is still the most thorough, comprehensive and broadly reviewed work on the oceans and fisheries subjects that has been published.

I led IPCC work on five impact analyses. For fisheries I was convening lead author; polar regions, co-chair; oceans, a lead author; and oceans and coastal zones, on two reports I was co-chair. In 1996, I received the NOAA Administrator's Award for accomplishments in assessing the impacts of climate change on global oceans and fisheries.

Since leaving NOAA I have been an IPCC reviewer and have talked to many individuals and groups and have maintained these subjects on climate change on the U.N. Atlas of the Oceans at OceansAtlas.org where I am the chief editor and project manager.

Professionally, I am also president of Ocean Associates, Inc., an oceans and fisheries consulting business, and two web-based businesses. OceansArt.us sells and shares ocean-related photos, and TechnologySite.org provides information and photos about inventions. Last, I have a website where I try to keep track of all the latest information about the soldiers in the climate change wars, and that is ClimateChange Facts.info.

I think it is time for a reality check. The oceans and coastal zones have been far warmer and colder than is projected in the present scenarios of climate change. Over millennia, marine life have endured and responded to CO_2 levels well beyond that have been projected and temperature changes that put coral reefs and tropical plants closer to the poles or had much of our land covered by ice more than a mile thick.

The memory of these events is built into the genetic plasticity of the species on this planet. Biological impacts will be determined by this plasticity and the resiliency of organisms to find suitable habitats. In the oceans, major climate warming and cooling is a fact of life whether it is over a few years, as in an El Niño, or over decades as in the Pacific Decadal Oscillation or the North Atlantic Oscillation.

Currents, temperatures, salinity and biology changes rapidly to the new state in months or a couple years. These changes far

exceed those expected with global warming and occur much faster. The one degree Fahrenheit rise since about 1860, indeed the same as the amount since the year 1000, has brought the global average temperature from 56.5 to 57.5 degrees. This is at the level of noise in this rapidly changing system.

Sea level has been rising since the last glaciation lost its grip, and temperatures rose by 10 to 20 degrees, a mere 10,000 years ago. It is only some few thousand years since Georges Bank was part of the mainland. It is now 60 miles offshore of Provincetown. Its trees and the shells of its oysters that flourished on its shores still come up in dredges and trawls in now very deep water, with the oysters looking like they were just shucked yesterday.

In the face of all these natural changes and those that we are here to consider, some species flourish while other diminish. These considerations were well understood in all the IPCC groups in which I participated.

I have some concerns about some few species near the margins of their suitable habitat range, such as polar bears, but I would much rather have the present warm climate and even further warming than the next ice age that would bring temperatures much colder than even today.

The NOAA PaleoClimate Program shows us on their website that when the dinosaurs roamed the earth, the earth was much warmer. The CO_2 levels were two to four times higher than today, and coral reefs were much more expansive. The earth was so productive then that we are still using the oil, coal and gas it generated.

More of the warming, if it comes, will be during winters and at night and toward the poles. For most life in the oceans, warming means faster growth, reduced energy requirements to stay warm, lower winter mortalities and wider ranges of distribution. Warming is not a big deal and is not a bad thing in the oceans.

No one knows whether the earth is going to keep warming or since reaching a peak in 1998 we are at the start of a cooling cycle that will last several decades or more. Whichever it is, our actions should be prudent.

Our fishing and maritime industries compete in a world market and are vulnerable to government actions to reduce CO_2 emissions. We already import most of our seafood, and our competitors do not need further advantages. Our ocean research should focus on things we need to do and to know to wisely manage our resources, our industries and our coastal areas no matter which way the wind blows in the years to come.

I also would be pleased to answer questions.

[The prepared statement of Dr. Everett follows:]

Statement of Dr. John T. Everett, President and Consultant, Ocean Associates, Inc.

Madam Chairwoman and Members of the Committee, thank you for inviting me to appear before you today. I am John Everett. I am not here to represent any particular organization, company, nor special-interest group. I have never received any funding to support my climate change work other than my NOAA salary, when I was employed there up to five years ago, in various positions over a 31-year career. I will present the results of the work I led for the Intergovernmental Panel on Climate Change from 1988 to 2000, while an employee of NOAA. This is still the most thorough, comprehensive, and broadly reviewed work on the subjects that has been published. The reports were reviewed by hundreds of government and academic

scientists as part of the IPCC process. My work included five impact analyses: Fisheries (Convening Lead Author), Polar Regions (Co-Chair), Oceans (Lead Author), and Oceans and Coastal Zones (Co-Chair/2 reports). Since leaving NOAA I have kept abreast of the literature, have talked to many individuals and groups and have maintained these subjects in the UN Atlas of the Oceans, where I am the Chief Editor and Project Manager. While I will present the results from IPCC documents I led or helped write, all opinions are mine alone, and are at the end.

Background.

I was assigned the climate change duties when I was the National Marine Fisheries Service Division Chief for Fisheries Development in the 1970s. The agency was very concerned about the impact of climate change on the United States fisheries and fishing industry. Global cooling. would be devastating to our fisheries and aquaculture. About 1987, the momentum shifted to fears of global warming and with my background, I was tasked to lead our efforts dealing with it. In 1996 I received the NOAA Administrator's Award for "accomplishments in assessing the impacts of climate change on global oceans and fisheries."

Taking only information from IPCC reports, essentially verbatim, I first present a summary, then more detail. The full reports are listed in the endnotes and have all the supporting text (about 60 pages) and hundreds of citations, which do not appear here.

Summary of Impacts

Fisheries

- Freshwater fisheries and aquaculture at mid to higher latitudes should benefit
- Saltwater fisheries should be about the same
- Fishery areas and species mix will shift
- Changes in abundance more likely near ecosystem boundaries
- National fisheries will suffer if fishers cannot move within and across national borders (Subsistence/small scale fishermen suffer most)
- Climate change impacts add to overfishing, lost wetlands and nurseries, pollution, UV-B, and natural variation
- Inherent instability in world fisheries will be exacerbated by a changing climate
- Globally, economic and food supply impacts should be small. In some countries, they could be large
- Overfishing is more important than climate change today; the relationship should reverse in 50-100 years (as overfishing is controlled)

Oceans

- Temperature changes will cause geographical shifts in biota and changes in biodiversity, and in polar regions the extinction of some species and proliferation of others.
- A temperature rise in high latitudes should increase the duration of the growing period and the productivity of these regions.
- Increased coral bleaching will occur as a result of a predicted 2°C increase in average global atmospheric temperature by 2050.
- The Northwest Passage and Northern Sea Route of Russia likely will be opened for routine shipping.
- Sea-level changes will occur with regional variations.
- Changes in coastal pollutants will occur with changes in precipitation and runoff.
- Changes in circulation and vertical mixing will influence nutrient availability and primary productivity, affecting the efficiency of carbon dioxide uptake by the oceans.
- The oceans' uptake and storage capacity for greenhouse gases will be affected by changes in nutrient availability resulting from other changes in precipitation, runoff, and atmospheric deposition.
- Freshwater influx from movements and melting of sea ice or ice sheets may lead to a weakening of the global thermohaline circulation, causing unpredictable instabilities in the climate system.
- Reduced yields of desirable fish species will occur if primary productivity decreases.
- Marine mineral extraction, except for petroleum hydrocarbons and the marine pharmaceutical and biotechnological industries, is insensitive to global climate change.

Polar Regions

- Major physical, ecological, sociological, and economic changes are expected in the Arctic, but much smaller changes are likely for the Antarctic.
- Substantial loss of sea ice is expected in the Arctic ocean. If there is more open water, there will be a feedback to the climate system of northern countries by moderating temperature and increasing precipitation.
- Polar warming probably should increase biological production, but may lead to different species composition. In the sea, marine ecosystems will move poleward. Animals dependent on ice may be disadvantaged.
- Human communities in the Arctic will be affected by the physical and ecological changes. Effects will be particularly important for indigenous peoples leading traditional lifestyles.
- There will be economic benefits and costs. Benefits include new opportunities for shipping across the Arctic Ocean, lower operational costs for the oil and gas industry, lower heating costs, and easier access for tourism. Increased costs can be expected from several sources including disruptions caused by thawing of permafrost and reduced transportation capabilities across frozen ground and water.
- Sea ice changes in the Arctic have major strategic implications for trade and defense.

The Impact of Climate Change.

The oceans and coastal zones have been far warmer and colder than is projected in the present scenarios of climate change. Marine life has been in the oceans nearly since when they were formed. During the millennia they endured and responded to CO_2 levels well beyond anything projected, and temperature changes that put tropical plants at the poles or had much of our land covered by ice more than a mile thick. The memory of these events is built into the genetic plasticity of the species on this planet. IPCC forecasts are for warming to occur faster than evolution is considered to occur, so impacts will be determined by this plasticity and the resiliency of affected organisms to find suitable habitats. In the oceans, major climate warming and cooling is a fact of life, whether it is over a few years as in an El Niño or over decades as in the Pacific Decadal Oscillation or the North Atlantic Oscillation. Currents, temperatures, salinity, and biology changes rapidly to the new state in months or a couple years. These changes far exceed the changes expected with global warming and occur much faster. The one degree F. rise since 1860 is virtually noise in this rapidly changing system. Sea level has been inexorably rising since the last glaciation lost its grip a mere 10,000 years ago. It is only some few thousand years since trees grew on Georges Bank and oysters flourished on its shores. Their remains still come up in dredges and trawls in now deep water, with the oysters looking like they were shucked yesterday. In the face of all these natural changes, and those we are here to consider, some species flourish while others diminish. These considerations were well understood in all the IPCC groups in which I participated.

The following text is taken from IPCC reports that I led. The text is left intact, with a very few edits to make complete sentences after deletion of portions irrelevant for this Hearing, such as some terrestrial impacts in the Arctic. Most background information has been deleted, but all these summary statements are fully supported in the cited references.

FISHERIES[1]

Convening Lead Author: John T. Everett, USA. Lead Authors: A. Krovnin, Russia; D. Lluch-Belda, Mexico; E. Okemwa, Kenya; H.A. Regier, Canada; J.-P. Troadec, France

Summary. Climate-change effects interact with those of pervasive overfishing, diminishing nursery areas, and extensive inshore and coastal pollution. Globally, marine fisheries production is expected to remain about the same; high-latitude freshwater and aquaculture production are likely to increase, assuming that natural climate variability and the structure and strength of ocean currents remain about the same. The principal impacts will be felt at the national and local levels as species mix and centers of production shift. The positive effects of climate change—such as longer growing seasons, lower natural winter mortality, and faster growth rates in higher latitudes—may be offset by negative factors such as changes in established reproductive patterns, migration routes, and ecosystem relationships.

- Globally, under the IPCC scenarios, saltwater fisheries production is hypothesized to be about the same, or significantly higher if management deficiencies are corrected. Also, globally, freshwater fisheries and aquaculture at mid- to higher latitudes could benefit from climate change. These conclusions are de-

pendent on the assumption that natural climate variability and the structure and strength of wind fields and ocean currents will remain about the same. If either changes, there would be significant impacts on the distribution of major fish stocks, though not on global production (Medium Confidence).

- Even without major change in atmospheric and oceanic circulation, local shifts in centers of production and mixes of species in marine and fresh waters are expected as ecosystems are displaced geographically and changed internally. The relocation of populations will depend on properties being present in the changing environments to shelter all stages of the life cycle of a species (High Confidence).
- While the complex biological relationships among fisheries and other aquatic biota and physiological responses to environmental change are not well understood, positive effects such as longer growing seasons, lower natural winter mortality, and faster growth rates in higher latitudes may be offset by negative factors such as a changing climate that alters established reproductive patterns, migration routes, and ecosystem relationships (High Confidence).
- Changes in abundance are likely to be more pronounced near major ecosystem boundaries. The rate of climate change may prove a major determinant of the abundance and distribution of new populations. Rapid change due to physical forcing will usually favor production of smaller, low-priced, opportunistic species that discharge large numbers of eggs over long periods (High Confidence). However, there are no compelling data to suggest a confluence of climate-change impacts that would affect global production in either direction, particularly because relevant fish population processes take place at regional or smaller scales for which general circulation models (GCMs) are insufficiently reliable.
- Regionally, freshwater gains or losses will depend on changes in the amount and timing of precipitation, on temperatures, and on species tolerances. For example, increased rainfall during a shorter period in winter still could lead to reduced levels in summer in river flows, lakes, wetlands, and thus in freshwater fisheries. Marine stocks that reproduce in freshwater (e.g., salmon) or require reduced estuarine salinities will be similarly affected (High Confidence).
- Where ecosystem dominances are changing, economic values can be expected to fall until long-term stability (i.e., at about present amounts of variability) is reached (Medium Confidence). National fisheries will suffer if institutional mechanisms are not in place that enable fishing interests to move within and across national boundaries (High Confidence). Subsistence and other small-scale fishermen, lacking mobility and alternatives, often are most dependent on specific fisheries and will suffer disproportionately from changes (Medium Confidence).
- Because natural variability is so great relative to global change, and the time horizon on capital replacement (e.g., ships and plants) is so short, impacts on fisheries can be easily overstated, and there will likely be relatively small economic and food supply consequences so long as no major fish stocks collapse (Medium Confidence).
- An impact ranking can be constructed. The following items will be most sensitive to environmental variables and are listed in descending order of sensitivity (Medium Confidence):
  - Freshwater fisheries in small rivers and lakes, in regions with larger temperature and precipitation change
  - Fisheries within Exclusive Economic Zones (EEZs), particularly where access-regulation mechanisms artificially reduce the mobility of fishing groups and fleets and their capacity to adjust to fluctuations in stock distribution and abundance
  - Fisheries in large rivers and lakes
  - Fisheries in estuaries, particularly where there are species without migration or spawn dispersal paths or in estuaries impacted by sea-level rise or decreased river flow
  - High-seas fisheries.
- Adaptation options with large benefits irrespective of climate change (Medium Confidence):
  - Design and implement national and international fishery-management institutions that recognize shifting species ranges, accessibility, and abundances and that balance species conservation with local needs for economic efficiency and stability
  - Support innovation by research on management systems and aquatic ecosystems
  - Expand aquaculture to increase and stabilize seafood supplies, help stabilize employment, and carefully augment wild stocks

- ○ In coastal areas, integrate the management of fisheries with other uses of coastal zones
- ○ Monitor health problems (e.g., red tides, ciguatera, cholera) that could increase under climate change and harm fish stocks and consumers.

Oceans[2]

Convening Lead Author: Venugopalan Ittekkot, Germany. Principal Lead Authors: Su Jilan, China; E. Miles, USA; Lead Authors: E. Desa, India; B.N. Desai, India; J.T. Everett, USA; J.J. Magnuson, USA; A. Tsyban, Russian Federation; S. Zuta, Peru

Summary. Global warming as projected by Working Group I of the IPCC will have an effect on sea-surface temperature and sea level. As a consequence, it is likely that ice cover and oceanic circulation will be affected, and the wave climate will change. The expected changes affect global biogeochemical cycles, as well as ecosystem structure and functions, on a wide variety of time and space scales; however, there is uncertainty as to whether extreme events will change in intensity and frequency. We have a high level of confidence that:

- Redistribution of temperatures could cause geographical shifts in biota as well as changes in biodiversity, and in polar regions the extinction of some species and proliferation of others. A rise in mean temperature in high latitudes should increase the duration of the growing period and the productivity of these regions if light and nutrient conditions remain constant.
- Sea-level changes will occur from thermal expansion and melting of ice, with regional variations due to dynamic effects resulting from wind and atmospheric pressure patterns, regional ocean density differences, and oceanic circulation.
- Changes in the magnitude and temporal pattern of pollutant loading in the coastal ocean will occur as a result of changes in precipitation and runoff.

We can say with a lesser degree of confidence that:

- Changes in circulation and vertical mixing will influence nutrient availability and primary productivity, thereby affecting the efficiency of carbon dioxide uptake by the oceans.
- The oceans' uptake and storage capacity for greenhouse gases will be affected further by changes in nutrient availability in the ocean resulting from other changes in precipitation, runoff, and atmospheric deposition.
- Freshwater influx from the movements and melting of sea ice or ice sheets may lead to a weakening of the global thermohaline circulation, causing unpredictable instabilities in the climate system.

The most pervasive effects of global climate change on human uses of the oceans will be due to impacts on biotic resources; transportation and nonliving resource exploitation will be affected to a lesser degree. We can say with a high level of confidence that:

- Increased coral bleaching will occur as a result of a predicted 2°C increase in average global atmospheric temperature by 2050.
- Expanded dredging operations will be necessary to keep major ports open in the Northern Hemisphere, which will increase costs.
- The Northwest Passage and Northern Sea Route of Russia likely will be opened up for routine shipping.
- Growth in the marine instrumentation industry will occur as the need for research and monitoring of climate change increases.

We can say with a lesser degree of confidence that:

- Reduced yields of desirable fish species will occur if average primary productivity decreases.
- If the frequency of tropical storms and hurricanes increases, adverse impacts will be generated for offshore oil and gas activities and for marine transportation in the tropics.
- Marine mineral extraction, except for petroleum hydrocarbons and the marine pharmaceutical and biotechnological industries, is insensitive to global climate change.

Adaptation to the impact of climate change on oceans is limited by the nature of these changes, and the scale at which they are likely to occur:

- No adaptive responses to coral bleaching, even on a regional scale, will be available if average global temperature increases 2°C by 2050. However, reductions in land-based pollution of the marine environment, combined with reductions in habitat degradation/ destruction, would produce benefits for fisheries, aquaculture, recreation, and tourism.
- Adaptation options will be available for the offshore oil, gas, and shipping industries if the frequency of tropical storms and hurricanes increases. The options include improved design standards for offshore structures, national and

international regulations for shipping, and increased technological capabilities to provide early warning at sea. Governments also can increase attention to institutions for planning and responding to disasters and emergencies.

- Where climate change generates positive effects, market-driven needs will create their own adaptation dynamic. However, adaptation policies will be required to control externalities that are market failures. For instance, opening up both the Northwest Passage and the Russian Northern Sea Route for up to 100 days a year—while a boon to international shipping and consumers in East Asia, North America, and Western Europe—will have to be accompanied by policies designed to limit the total burden of pollutants entering the Arctic environment from ports, ship operations, and accidents.

A combination of human activities (e.g., overfishing, pollution of estuaries and the coastal ocean, and the destruction of habitat, especially wetlands and seagrasses) currently exerts a far more powerful effect on world marine fisheries than is expected from climate change.

In contrast to model projections, observations over large parts of the tropical Atlantic between 1947 and 1986 have shown an increase in the trade winds. Bakun suggests that the greenhouse effect will enhance the seasonal warming of continents—leading to a decrease in the pressure over land, an increase in the land—sea pressure difference, and increased alongshore winds. Binet has observed such effects along the coast of northwest Africa. It appears likely that the strength of both oceanic and coastal upwelling mechanisms could change under conditions of global warming, with profound impacts upon fish species and their production as well as on the climate of the immediate coastal zone.

Although ENSO is a natural part of the Earth's climate, a major question is whether the intensity or frequency of ENSO events might change as a result of global warming. Historical and paleorecords reveal that ENSO events have changed in frequency and intensity in the past on multidecadal to century timescales. It is unclear whether ENSO might change with long-term global warming.

Sea ice covers about 11% of the ocean, depending on the season. It affects albedo, salinity, and ocean-atmosphere thermal exchange. The latter determines the intensity of convection in the ocean and the timescale of deep-ocean processes affecting CO_2 uptake and storage.

Projected changes in climate should produce large reductions in the extent, thickness, and duration of sea ice. Major areas that are now ice-bound throughout the year are likely to have major periods during which waters are open and navigable. Some models even predict an ice-free Arctic. Melting of snow and glaciers will lead to increased freshwater influx, changing the chemistry of those oceanic areas affected by the runoff. There is no convincing evidence of changes in the extent of global sea ice. Studies on regional changes in the Arctic and Antarctic indicate trends of decadal length, often with plausible mechanisms proposed for periodicities of a decade or more. Longer data sets are needed to test if a genuine long-term trend is developing.

Winds and waves are the major forcing factors for vertical mixing; the degree of mixing depends on the vertical density structure. In the past 40 years, there has been an increase in the mean wave height over the whole of the North Atlantic, although it is not certain that global change is the cause of this phenomenon.

Metabolic rates, enzyme kinetics, and other biological characteristics of aquatic plants and animals are highly dependent on external temperatures; for this reason alone, climate change that influences water temperature will have significant impacts on the ecology and biodiversity of aquatic systems. The capability of some species to adapt genetically to global warming will depend on existing genetic variation and the rapidity of change. Species remaining in suboptimal habitats should at least experience reductions in abundance and growth well before conditions become severe enough for extinctions to occur. The resilience of an ecosystem to climate change will be determined to a large extent by the degree to which it already has been impaired by other human activities.

Coastal ecosystems are especially vulnerable in this context. They are being subjected to habitat degradation; excessive nutrient loading, resulting in harmful algal blooms; fallout from aerosol contaminants; and emergent diseases. Human interventions also have led to losses of living marine resources and reductions in biodiversity from biomass removals at increasingly lower trophic levels. The effects on biodiversity are likely to be much less severe in the open ocean than in estuaries and wetlands, where species in shallow, restricted impoundments would be affected long before deep-oceanic species.

The chief biotic effects on individuals of an increase in mean water temperature would be increased growth and development rates. If surface temperatures were correlated positively with latitude, and temperature increased, one would expect a

poleward shift of oceanic biota. While this may be the general case, there could be important regional variations due to shifts in atmospheric and oceanic circulation. The resulting changes in predator-prey abundance and poleward shifts in species' ranges and migration patterns could, in the case of marine fisheries, lead to increased survival of economically valuable species and increased yield. Such cases have been observed as a result of the large and intense 1983 El Niño.

In high latitudes, higher mean water temperature could lead to an increase in the duration of the growing period and ultimately in increased bioproductivity in these regions. On the other hand, the probability of nutrient loss resulting from reduced deep-water exchange could result in reduced productivity in the long term—again highlighting the importance of changes in temperature on patterns of circulation. Global warming could have especially strong impacts on the regions of oceanic subpolar fronts, where the temperature increase in deep water could lead to a substantial redistribution of pelagic and benthic communities, including commercially important fish species.

Most migratory organisms are expected to be able to tolerate changes, but the fate of sedentary species will be dependent on local climate changes. Some corals would be affected (as in the 1983 and 1987 bleaching events), but it is expected that other stresses (e.g., pollution, sedimentation, or nutrient influx) may remain more important factors. Intertidal plants and animals, such as mangroves and barnacles, are adapted to withstand high temperature, and unless the 1.5°C increase affects reproduction, it will have no effect. Similarly, only seagrass beds already located in thermal-stress situations (i.e., in shallow lagoons or near power plant effluents) are expected to be negatively affected by the projected temperature rise. One cannot rule out, however, the possibility of significantly greater tropical warming than 1.5°C. For example, some investigators argue that tropical warming was approximately 5°C from the last glacial maximum to today. If this value is correct, current GCMs probably underestimate tropical sensitivity.

Changes in temperature and salinity are expected to alter the survivorship of exotic organisms introduced through ballast water in ships, especially those species with pelagic larval forms. Introduction of exotic species is a form of biological pollution because, from a human perspective, they can have adverse impacts on ecosystems into which they are introduced and in some cases pose hazards to public health. A classic recent example of the spread of an introduced exotic species is that of the zebra mussel (Dressena polymorpha), which was transported to the Great Lakes via transatlantic shipping from the Baltic sea. Changes in temperature could enhance the potential for the survival and proliferation of exotic species in environments that are presently unfavorable.

Changes also can be expected in the growth rates of biofouling organisms that settle on means of transport, conduits for waste, maritime equipment, navigational aids, and almost any other artificial structure in the aquatic environment. Their species distributions often are limited by thermal and salinity boundaries, which are expected to change with regional changes in temperature and precipitation. Areas that experience warming and reduced precipitation (i.e., salinity increases) likely will have increased problems with biofouling.

Predicted climate change also may have important impacts on marine mammals such as whales, dolphins, and seals, and seabirds such as cormorants, penguins, storm petrels, and albatross. However, it is presently impossible to predict the magnitude and significance of these impacts. The principal effects of climate change on marine mammals and seabirds are expected from areal shifts in centers of food production and changes in underlying primary productivity due to changes in upwelling, loss of ice-edge effects, and ocean temperatures; changes in critical habitats such as sea ice (due to climate warming) and nesting and rearing beaches (due to sea-level rise); and increases in diseases and production of oceanic biotoxins due to warming temperatures and shifts in coastal currents.

Ice plays an important role in the development and sustenance of temperate to polar ecosystems because it creates conditions conducive to ice-edge primary production, which provides the primary food source in polar ecosystems; it supports the activity of organisms that ensure energy transfer from primary producers (algae and phytoplankton) to higher trophic levels (fish, marine birds, and mammals); and, as a consequence, it maintains and supports abundant biological communities.

One of the possible beneficial consequences of global warming might be a reduction in the extent and stability of marine ice, which would directly affect the productivity of polar ecosystems. For example, the absence of ice over the continental shelf of the Arctic Ocean would produce a sharp rise in the productivity of this region, provided that a sufficient supply of nutrients is maintained. Changes in water temperature and wind regimes as a result of global warming also could affect the distribution and characteristics of polynyas (ice-free areas), which are vital to polar

marine ecosystems. In addition, changes in the extent and duration of ice, combined with changes in characteristics of currents—for example, the circumpolar current in southern latitudes—may affect the distribution, abundance, and harvesting of krill. Krill are an important link in the ocean fauna in the Southern Ocean. It is important to understand how, when, and where productivity in the Southern Ocean will change with global warming.

A number of marine organisms depend explicitly on ice cover. For example, the extent of the polar bear's habitat is determined by the maximum seasonal surface area of marine ice in a given year. The disappearance of ice would threaten the very survival of the polar bear, as well as certain marine seals. Similarly, a reduction in ice cover would reduce food supplies for seals and walruses and increase their vulnerability to natural predators and human hunters and poachers. Other animals, such as the otter, could benefit by moving into new territories with reduced ice. Some species of marine mammals will be able to take advantage of increases in prey abundance and spatial/temporal shifts in prey distribution toward or within their primary habitats, whereas some populations of birds and seals will be adversely affected by climatic changes if food sources decline or are displaced away from regions suitable for breeding or rearing of young.

Animals that migrate great distances, as do most of the great whales and seabirds, are subject to possible disruptions in the distribution and timing of their food sources during migration. For example, it remains unclear how the contraction of ice cover would affect the migration routes of animals (such as whales) that follow the ice front. At least some migrating species may respond rapidly to new situations.

While the impacts of these ecological changes are likely to be significant, they cannot be reliably forecast or evaluated. Climate change may have both positive and negative impacts, even on the same species. Positive effects such as extended feeding areas and seasons in higher latitudes, more-productive high latitudes, and lower winter mortality may be offset by negative factors that alter established reproductive patterns, breeding habitat, disease vectors, migration routes, and ecosystem relationships.

Polar Regions: Arctic/Antarctica[3]

Convening Lead Authors: J.T. Everett (USA) and B. Blair Fitzharris (New Zealand)

Lead Author: Barrie Maxwell (Canada)

Summary. Direct effects could include: ecosystem shifts, sea and river ice loss, and permafrost thaw. Indirect effects could include positive feedback to the climate system. There will be new challenges and opportunities for shipping, the oil industry, fishing, mining and tourism, infrastructure, and movement of populations, resulting in more interactions and changes in trade and strategic balance. There will be winners and losers. As examples, a reduced and thinning ice cover will disadvantage polar bears, while sea otters will have new habitats; communities on new shipping routes will grow while those built on permafrost will have difficulties. Native communities will face profound changes impacting on traditional lifestyles.

- Major physical, ecological, sociological, and economic changes are expected in the Arctic, but much smaller changes are likely for the Antarctic, over the period of this assessment.
- Substantial loss of sea ice is expected in the Arctic ocean. If there is more open water, there will be a feedback to the climate system of northern countries by moderating temperature and increasing precipitation. If warming occurs, there will be considerable thawing of permafrost leading to changes in drainage, increased slumping and altered landscapes over large areas.
- Polar warming probably should increase biological production, but may lead to different species composition. In the sea, marine ecosystems will move poleward. Animals dependent on ice may be disadvantaged.
- Human communities in the Arctic will be affected by these physical and ecological changes. Effects will be particularly important for indigenous peoples leading traditional lifestyles.
- There will be economic benefits and costs. Benefits include new opportunities for shipping across the Arctic Ocean, lower operational costs for the oil and gas industry, lower heating costs, and easier access for tourism. Increased costs can be expected from several sources including disruptions caused by thawing of permafrost and reduced transportation capabilities across frozen ground and water.
- Sea ice changes in the Arctic have major strategic implications for trade and defense.

Marine Ecological Systems. If warming should occur, there will be an increase in growth and development rates of non-mammals. In general, productivity should rise. Risks include the loss of sea ice cover upon which several marine mammals depend for food and protection. Also, Arctic shipping, oil exploration and transport, and economic development could bring risks to many species.

- **Ice.** If there is warming, the Arctic could experience a thinner and reduced ice cover, including that in Arctic lakes and streams. In contrast, the vast Antarctic is so cold that any warming within the IPCC scenarios should have little impact except in the Dry Valleys and on the Antarctic Peninsula. In fact, ice could accumulate through greater snowfall, slowing sea level rise.
- **Permafrost.** Permafrost underlies as much as 25% of the global land surface. Considerable amounts will disappear, causing major changes in ecosystem structure and in human impacts.
- **Fisheries.** Warming could lead to a rise in production, unless changes in water properties would disrupt the spawning grounds of fish in high latitudes. There could be a substantial redistribution of important fish species. Fisheries on the margin of profitability could prosper or decline. Fishing seasons will lengthen, but most stocks are already fully exploited.
- **Navigation and Transport.** If sea-ice coverage is reduced, coastal and river navigation will increase. Opportunities for water transport, tourism, and trade will increase. The Arctic Ocean could become a major trade route. Seasonal transport across once frozen land and rivers may become difficult or costly. Offshore oil production should benefit from less ice.
- **Arctic Settlements.** If the climate ameliorates, conditions will favor the northward spreading of agriculture, forestry, and mining, with an expansion of population and settlements. More infrastructure such as marine, road, rail, and air links would be required. Changes in the distribution and abundance of sea and land animals will impact on traditional lifestyles of native communities.

WORLD OCEANS AND COASTAL ZONES[4]

Co-Chairs: John. Everett USA; Alla Tsyban (Russia); Jim Titus (USA)

World Oceans And Coastal Zones: Ecological Effects[5]

Co-Chairs: John. Everett USA; Alla Tsyban (Russia); Martha Perdomo (Venezuela)

These two report's findings were incorporated into subsequent reports and are included above, with the possible exception that these made a stronger case for the impacts of sea level rise. Since the projected amount of rise has now been rolled back in the latest scientific assessment due to a lack of acceleration in sea level rise, these findings are no longer relevant. Some of their adaptation recommendations are included below.

Research Needs

Information is most valuable if there are institutions and management mechanisms to use it. Research on improved mechanisms is needed so that fisheries can operate more efficiently with global warming as well as in the naturally varying climate of today. There is relatively little research underway on such mechanisms. Knowledge of the reproductive strategies of many species and links between recruitment and environment is poor.

The following items are needed specifically because of climate change. Other types of research, which are prerequisites for dealing with such concerns but which support the day-to-day needs of fisheries managers or relate more to understanding how ecosystems function, are not included.

- Determine how fish adapt to natural extreme environmental changes, how fishing affects their ability to survive unfavorable conditions, and how reproduction strategies and environments are linked. Link fishery ecology and regional climate models to enable broader projections of climate-change impacts and improve fishery management strategies.
- Implement regional and multinational systems to detect and monitor climate change and its impacts—building on and integrating existing research programs. Fish can be indicators of climate change and ecological status and trends. Assemble baseline data now so comparisons can be made later.
- Develop ecological models to assess multiple impacts of human activities.
- Determine the fisheries most likely to be impacted, and develop adaptation strategies.
- Assess the potential leaching of toxic chemicals, viruses, and bacteria due to sea-level rise and how they might affect both fish and the seafood supply.
- Determine institutional changes needed to deal with a changing climate. Such changes are likely the same ones needed for mastering overfishing and coping

with the variability and uncertainty of present conditions. Improved institutions would probably reduce stock variability more than climate change would increase it.
- Study the historical ability of societies to adapt their activities when their resources are impacted by climate changes.
- Research activities to better understand processes in the oceans, in particular the role of the oceans in the natural variability of the climate system at seasonal, interannual, and decadal to century timescales.
- Long-term monitoring and mapping of: water-level changes, ice coverage, and thermal expansion of the oceans; sea-surface temperature and surface air temperature; extratropical storms and tropical cyclones; changes in upwelling regimes along the coasts of California, Peru, and West Africa; UV-B radiation, particularly in polar regions, and its impact on aquatic ecosystems; regional effects on distribution of species and their sensitivity to environmental factors; changes in ocean biogeochemical cycles.
- Socioeconomic research activities to document human responses to global change

Adaptation Options

- Establish management institutions that recognize shifting distributions, abundances and accessibility, and that balance conservation with economic efficiency and stability
- Support innovation by research on management systems and aquatic ecosystems
- Expand aquaculture to increase and stabilize seafood supplies and employment, and carefully, to augment wild stocks
- Integrate fisheries and CZ management
- Monitor health problems (e.g., red tides, ciguatera, cholera)
- Coastal planners and owners of coastal properties and infrastructure should carefully consider projected relative sea level changes when evaluating new or reconstruction projects.
- Coastal planners and environmental decision-makers should consider that a healthy environment is a prerequisite for coral reefs, mangroves and sea grasses to keep pace with a rising sea and to continue their coastal protection benefits

Understanding Climate Change in Order to Assess Impacts—My View

My specialty that is relevant to this hearing is in impacts assessment, not the science of climate change. However, to determine impacts correctly, one must understand the nature of change and its likelihood to continue. In the IPCC structure, the science has been led by the UK and U.S. scientists, and they used modeling as their primary tool, with some paleoclimate analysis coming later. The Impacts Assessments were led by the Russians, who had an intense distrust of modeling. They viewed paleoclimatology as the most valid tool: if you want to know what will happen when CO_2 rises or the temperature changes, look at the history of the earth. As an American, working with the Russian teams, I was often caught in the middle of both camps. I learned to listen to both views, and continue to do so. In particular, we learned to distrust any science literature or impacts assessment that did not consider all data available, whether modeling, the instrumented record back into the 1800s and/or the paleo and historical temperature reconstructions. If the data are truncated, there is likely an agenda.

In this light I view with grave concern the two latest IPCC Summary for Policy Makers which use truncated data in text and graphics to misrepresent the amount of warming, causing undue alarm. For example, from the most recent SPM, "The Working Group I Fourth Assessment concluded that most of the observed increase in the globally averaged temperature since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations... " This is a red flag. It begs the question of why the restriction "since the mid-20th century". What is wrong with the full data set back into the 1800s? Is it restricted to "mid-20th century" because it is too difficult to explain the prior decades of falling temperatures in the face of rising CO_2? This demonstration (and there are many others) is typical of what has led many disagreeing scientists to not be invited to IPCC anymore, and others to lose interest. Over 20 years the core IPCC-participating scientists have become more homogeneous. The consensus has become stronger as dissenting scientists have moved to become the "other consensus", usually called climate skeptics.

The source of the warming or cooling is of little importance to an impacts assessment, except where it provides a clue as to future trends. Most people agree that

there has been a warming of 1 degree Fahrenheit in the instrumental record of 150 years. Those in the "IPCC-oriented consensus" believe it is due to mankind's increased CO_2 and other gas emissions; therefore temperatures are likely to rise as more humans inhabit the earth and economies grow. This is important information to a specialist in assessments. Also important, though, is staying in touch with other views. Scientists in the "other consensus" believe that, even if the 1 degree change is accurate (and is not just "noise"), the CO_2 rise can, at most, explain a piece of the temperature rise. Many believe that increased water vapor, solar variations in radiation and magnetic flux, our relative position in the solar system, the tilt of our planet's axis, the clearing of our atmosphere of pollutants which allows more sunlight to reach the ground, or our position in the Milky Way galaxy that affects the amount of radiation reaching our atmosphere and affecting cloud formation, are also important and are not (and cannot be yet) adequately considered in the computer models used by the IPCC consensus. Many believe CO_2 may not be the culprit.

Concluding Remarks

Personally, I do not know whether the earth is going to continue to warm, or that having reached a peak in 1998, we are at the start of a cooling cycle that will last several decades or more. Whichever it is, our actions should be prudent. Our fishing industry, maritime industry and other users of the ocean environment compete in a world market and are vulnerable in many ways to possible governmental actions to reduce CO_2 emissions. We already import most of our seafood and many of the nations with which we compete do not need further advantages. Our research should focus on those ecosystem linkages we need to understand in order to wisely manage our fisheries, and this includes the ability to incorporate natural climate variability along with long term changes. Institutionally, we should work with our neighbors to pre-determine what should happen when one of our major fish stocks ignores the international boundary. Lastly, I would like to draw the Committee's attention to the testimony of Dr. Steven Murawski, of NMFS, at a hearing on Projected and Past Effects of Climate Change: a Focus on Marine and Terrestrial Ecosystems before the Senate Committee on Commerce, Science and Transportation, Subcommittee on Global Climate Change and Impacts, on April 26, 2006. I think it is well done, although I would quibble with some minor points..

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Response to questions submitted for the record by Dr. John Everett, 13 May 2007

Dear Chairwoman Bordallo,

Thank you very much for the opportunity to participate in the hearing and to provide responses to the follow-up questions.

I worked with the Intergovernmental Panel on Climate Change (IPCC) from 1988 to 2000 on five impact analyses: Fisheries (Convening Lead Author), Polar Regions (Co-Chair), Oceans (Lead Author), and Oceans and Coastal Zones (Co-Chair/2 re-

ports). Since leaving NOAA, I have remained an Expert Reviewer within the IPCC system.

I support the IPCC process. It is a reasonable way to coordinate the development of policy advice on global issues. However, there does appear to be "cherry picking" of science and results to advance some agendas. The growing body of scientists outside the IPCC process often come to different conclusions based on the same science, and their concerns are not fully considered. Having difficulty myself in ferreting out the facts, I have kept track of information from both camps, eventually putting it on a website so I could access it anywhere. I have recently made it available to everyone at http://www.ClimateChangeFacts.info.

I believe we are on the wrong path. The worst-case impacts, from worst-case scenarios, that have been run through an under-achieving model are insufficiently discounted in the IPCC reports vis-à-vis better analyses. The result is a gross exaggeration of impacts in the press. We do not hear about minor impacts and benefits, only the "newsworthy" elements. To do realistic impact assessments, I have to sort through the science and projections. A summary of considerations that shaped my written statement and this response to your questions are that:

- The Earth's natural processes also contribute, and remove, CO_2. Since plants first appeared on the Earth, they have converted nearly all available CO_2 to oxygen, fossil fuels, and to other long-term storage. Today, less than 4/10 of 1% (379 ppm) of our atmosphere is CO_2, a small amount relative to other periods in Earth's history. Some popular IPCC scenarios include rising CO_2 (2%/year) from an increasing supply of fossil fuels for 100 years, yet we know that this is improbable. Production will soon peak (if not already) and prices are rising.
- The projected temperature rise defies logic, given that the USA and global temperatures have risen by (at most) only 1 deg F (.5 C) in 100 years (NOAA, May 2007), during the height of industrial expansion. This is a trivial amount in the natural variation of the Earth, and to suggest the rise would accelerate 5 fold (IPCC best estimate) in this century is incredible. NOAA's new data set, released on May 1, addressed some of the urban heat island issues, dropping the warming 44% (below IPCC 2007), but significant other data issues still remain. Also, the Earth was much warmer in the prior interglacial, just 125,000 years ago.
- The IPCC 2007 rate of sea level rise adds 1 mm/year to the 1-2 mm/year that has been happening in recent centuries. This additional amount is only 4 inches over 100 years.
- Other projections, such as for hurricanes, rainfall, and snow cover, are not significantly different than under natural variability, and most will advance more slowly than the decadal oscillations. With regard to ocean acidity, shell formation problems should have shown up already in areas where there are naturally high levels of CO_2. They have not.

Above all, the IPCC Impact Assessment discounts the benefits that come with a warming climate and accentuates the negatives. Most negatives lie within the unrealistic worst case climate scenarios. Whether a fish in the ocean, a shrimp in a pond, or a bean on a vine, it will grow faster when it is warmer, all things being equal. Humans will be quick to take advantage of a warmer climate. More crops grow where it is warm than in frozen ground, and CO_2 is a primary food of plants—basic facts that seem lost in this discussion. However, the impact is visible to NASA satellites, which have detected a 6% greening of the Earth in the last 2 decades from a warmer, wetter, higher-CO_2 Earth (NASA 2003). Findings like this are rarely highlighted in IPCC SPM documents.

Supporting details for the above and for my responses are on my website. I would be pleased to elaborate further, if requested.

Sincerely,

Dr. John T. Everett
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QUESTIONS FROM THE HONORABLE MADELEINE BORDALLO, CHAIRWOMAN

In your testimony you note that a combination of human activities including overfishing, pollution of estuaries and the coastal ocean, and the destruction of habitat-particularly wetlands and seagrasses-currently exert a far more powerful effect on world marine fisheries than is expected from climate change.

1. Do you think we are currently doing enough to address those problems here in the United States? If not, can you elaborate on what we should be doing differently?

I think we are putting about the right amount of resources into these issues, but we could do more if we weren't hampered by our institutional arrangements. I think the people in NOAA, the states, EPA, the Corps, and all the other bodies are working hard towards achieving the correct goals, but that institutional barriers are more of a hindrance than lack of funding. For a dozen years I was Director of NMFS Policy and Planning. I was also a Senate staffer and during that time I led the negotiations on behalf of both Houses on the first reauthorization of the FCMA. I also have been closely affiliated with FAO since 1999. These are some of the experiences underlying my view. We have had over 30 years to get it right and we are not there yet. This, alone, serves as a reality check for the merits of the system we have established.

I have always said that if I were Prince of Fish, I would do things much differently. Our problem in managing fisheries is that we live in a democracy where authority is diffuse and nearly everything requires negotiation. This may lead to a better solution, but everything takes a long time to accomplish and the driving force is usually some disaster, whether a crashed stock or some ecosystem imbalance which disrupts normal function, such as sharks replacing codfish. Sometimes there are stalemates that may prevent rational management.

The different entities involved in resource management, such as communities, counties, states, tribal organizations, state commissions, Councils, international treaty bodies, and bilateral organizations all complicate the process. As much as I admire our system of government, I think it sometimes brings chaos to resource management. Imagine for a moment having one agency (or a Prince) responsible for all fisheries throughout their range, able to cut across all agency fiefdoms. There would be no hiding behind some perceived failure of somebody else. If there is mismanagement, we know who is responsible and if something needs to be done, we know who gets the task. So, if we want to do something dramatic, that reduces the cost and inefficiencies in the existing system, I think we should start with a clean slate, design an ideal system, then modify our institutions to accommodate it. This will require a very heavy hand indeed.

2. Dr. Everett, like Bill McKibben, you acknowledge that a changing climate will produce winners and losers. Yet unlike Mr. McKibben, who views climate change as an opportunity to transform our society into a 21st Century "Green Economy" which will produce many more winners than losers, you seem satisfied to tinker around the edges the status quo to avoid taking potentially unnecessary changes to address the problem.

I support moving towards a Green Economy, and working to reduce our dependence on fossil fuels is a valid objective within this ideal. However, it may or may not be important to the Earth's climate system. Let us not forget that just a few years ago, many of the same NGOs who are alarmed about warming and CO_2 emissions, were arguing with the same fervor that our fossil fuels were running out. Many still are. It can't be both ways—using more for decades and running out in a few years. There are probably not enough fuels left in the ground to allow the forecast acceleration of their consumption. We are seeing some price increases now, across all fuels, and even for corn, driven by the shortage of fossil fuels. I believe this will continue and will accelerate remarkably in the decades to come, greatly restricting CO_2 emissions. The market place and the finite resources will largely reduce consumption, but we should also subsidize research to clean up coal (and other difficult fuels) consumption throughout the world. I was alarmed by some of my fellow panelists who advocated cessation of coal production. We hold the world's largest inventories of coal and it is a major competitive advantage. We need to make it more environmentally friendly and use it.

The green economy goal is excellent and I agree with it, but it cannot be reached in one country alone because there is a world marketplace. When there are equal or lower costs, this is great for all of us. If we move to wind power by legislative fiat, on the other hand, and the production costs in our factories rise, our jobs will

migrate overseas even faster than at present. Thus, we run the very real risk of having far more losers than winners in the USA if we respond to this threat in an unwise way.

I am glad you consider me to be "tinkering". Tinkering is good, provided you have established goals. It is one of the best strategies for dealing with a complex problem such as this (Lindblom, 1959) where the issue is fuzzy at best, the correct course of action is uncertain, and a wrong course is perilous. We do not know enough to put all our eggs in the global warming catastrophe basket. Any eggs we put there should be refundable and of value on other objectives, such as energy independence and efficiency, and leaving some fossil fuels in the ground for use by future generations.

I grew up as a fisherman, learning from my father the need to put the little clams and lobsters back gently, and to protect them from predators while we could. I am very conscious of our role as a good steward of the Earth and have practiced stewardship all my life.

I am concerned we are at the verge of a potential colossal public policy failure that will damage our economy. This is a similar situation to that of several decades ago when uninformed hysteria led to halting the growth and technological advancement of our nuclear power industry. Other nations, such as France, with no significant fossil fuels, continued on the nuclear path, soon replacing us as exporters of nuclear technology and gaining clean electrical power that is largely from nuclear sources. We were left only with a fossil fuels option and now we are in a catch-up mode.

3. Your position seems contrary to our Nation's history of boldly confronting new challenges. Why are you advocating for a more cautious and incremental approach? Do you believe that our Nation is not up to this daunting task?

The daunting task is to keep ourselves informed and cautious in the face of seemingly overwhelming evidence that global warming is man-induced and that it is harmful. I am not convinced either is true. In fact both are probably mostly false. Therefore, we must move cautiously on things that will cost us competitive advantage in the marketplace, but expeditiously on things that make sense in their own right. This is an adaptive, incremental approach following the teachings of Charles Lindblom, 1959. If there is warming, things will be different, not worse, just as they are different whenever the Atlantic Oscillation and the Pacific Oscillation and the ENSO (El Niño Southern Oscillation) change phase, with far greater (and immediate) temperature and wind changes than are forecast by IPCC models. The easiest way to see this is to consider what might happen if the temperature were to be falling, which it just might be since reaching the latest peak in 1998. Just a slight cooling would largely destroy our agriculture (as we know it)—yet a slight warming would mean faster growth, and longer, more productive seasons. This is evident from NASA satellites showing a 6% increase over the last 20 years in the greenness of the earth. Further, the Earth's temperature has been higher and the CO_2 has been higher many times in the past, certainly during the last time we were between ice ages, and perhaps since the last one ended just 10,000 years ago.

On my website (http://www.ClimateChangeFacts.info), I explain this in considerable detail, providing the claims of scientists who think we are having unprecedented warming and that it is caused by humans. I also have the non-trivial counter claims by those who disagree on both aspects, with links to resources supporting all the views and ideas. I also have a series of items I believe we should do whether the Earth is warming or cooling and whether or not mankind's small contribution to the total CO_2 budget matters or not. I also have a series of items we should not do. Since these latter items are more important, for the present discussion, I will start with them first.

What Actions Should We Not Take to Respond to Climate Change?

We must respond prudently to the threats from climate change. We live in a global economy, much of it with lower production costs than our own in the developed world. Whether we live in the USA, Japan, Australia, New Zealand or the EU, we know our job losses are draining our countries, making it more difficult to support our retirement programs, health benefits, schools, and even our national defense. We must not exacerbate the high costs of our products and services. So we——

- Should not commit to actions that put us at a competitive disadvantage in the world market for goods and services, whether it is through the Kyoto protocol or some other vehicle;
- Should consider that if a taxing regime is implemented to discourage use of fossil fuels, it must separate production uses (such as manufacturing, agriculture,

and fishing) from personal consumption such as in home heating, and for personal cars used for discretionary travel. We should not place taxes on inputs to production and services that will hurt our ability to compete in the global market place.

- Should not forget that the most valuable things we have are our health, our lives, and our family, and we should not place them at risk by driving, or riding in, vehicles that put ourselves at risk in order to save energy or other costs.
- Should not stop breathing even though it would be one of the most immediate steps to slow CO_2 emissions.
- Should not do things without thinking. There are many ideas that may not have merit. For example, buying local vegetables to reduce transportation costs may actually increase energy use if the far off producer is more fuel efficient. Another example is in using biofuels that have a high fossil energy input in fertilizer or machinery, or planting trees to reduce CO_2, but finding out they also absorb solar radiation (heat) more than what they replace.

What Actions Should We Take to Respond to Climate Change?

We should respond prudently to the threats from climate change. Our actions should include things that make sense in their own right and which will be important whether the Earth warms or cools in the near future, or continues about the same until the next ice age arrives some 30,000 years or so in the future, according to our present knowledge of solar variability and orbital mechanics (IPCC 2007). We should aim to reduce the production costs in our industries and, at the consumer level, our living expenses, while at the same time "cleaning up our act" in the amount and type of energy we consume. Here is what we should do now:

- Lead by personal example. One way to check progress? Look at your household energy consumption. It should be dropping steadily over the years through
  - household maintenance and upgrading of insulation
  - appliance replacement and replacing light bulbs with fluorescents (all lights on timers, for example, should be fluorescents.
  - adjusting the thermostat for when nobody is home or awake
  - limiting our shower from being just a little too long
  - getting a watt-hour meter and seeing what each home appliance, electronics, and plug-in light costs to run.
  - reducing the number of parasitic loads. If a TV or VCR or Cable TV Box is sitting in the basement, and is rarely used, put it on a powerstrip and shut everything off when you leave the room.
  - getting an energy audit, particularly if it is free from the power company.
  - considering energy efficiencies on all appliances and vehicles.
  - check our home's water heater, or the pipes leaving it. If hot, insulate them. It is not just a loss of energy, but in the summer, the heater is fighting the air conditioner.
  - Shut off the light when it is not being used. Put your computer to sleep or shut it off (and all the peripherals).
  - Use fans and open windows for cooling.
  - When the air conditioner is on, be extra careful about adding heat that then has to be removed, doubling the amounts of energy used, and often at the higher "summer rate".
- Build our reliance on domestic energy sources. This includes the green technologies of wind, solar, hydro, nuclear, and tidal and recycling sources such as biogas and municipal solid waste. It also includes fossil fuels (from the time the Earth was really warm and productive), coal, oil, and gas—but in as clean a mode as possible. We need to be mindful that wind and solar are intermittent sources and require a backup supply AND a larger electrical grid (with more transmission lines and towers) than any other source.
- Conserve our energy through efficiency in all we do. This includes mundane things such as multipurpose trips when we run our errands or visit our clients.
- Make mass transit more extensive, more economical, and user friendly.
- Review building codes to ensure new homes and buildings are constructed to be more energy efficient, perhaps having different grading levels (with payback periods estimated) so purchasers can choose how far above a threshold value they wish to go. Standards for commercial buildings need to consider the global economy and whether production costs will be increased. Innovative ideas, such as using waste water from restroom sinks, or laundry machines, to flush toilets on lower floors, need to be considered.
- Implement consumer education programs at all levels, particularly within commercial establishments that produce goods and services. For example: provide energy saving tips, and management advice and software to truck and auto-

mobile fleet owners, to fishing vessel and maritime vessel owners, and highway designers.
- Develop and disseminate practical energy conservation packages for the general population and for industry sectors such as agriculture, trucking, airline, fishing, mining, refining, warehousing. These packages should contain reasonable energy reduction targets, milestones and estimates of savings if achieved.
- Review traffic flow measures that cause vehicles to stop and go, or wait unnecessarily for non-existent pedestrians or intersecting traffic.
- Vehicles: share rides in a car pool; inflate tires properly; time for a tuneup with new sparkplugs?; air filter dirty?; unnecessary weight in the trunk?
- Pay or subsidize research on all the above energy forms, particularly big ticket items such as nuclear and coal and on efficiencies in how we use power.
- Conserve our energy through less use of machinery. Examples are using clothes lines for drying, walking or riding a bike to work or for neighborhood errands and visits, using the stairs instead of elevators, forgetting about motorboats and buying sail boats, and putting down the leaf blower and picking up the rake.
- Make it easy everywhere for excess energy to be added to the electricity grid by consumers and industry with permanent or temporary excess power, such as from wind, methane, hydro, and solar—and at reasonable rates, at or near the highest rate tier actually being used at the time. This provides incentive to oversize individual production systems, leading to extra robustness in the overall grid.
- Foster new residential and commercial construction near mass transportation hubs, such as subway and railroad stations, airports, and bus terminals.
- Ensure that all our communities have safe routes where people can walk or bike to work, or at least use motorbikes safely. Highway and bridge rebuilding projects should provide dedicated lanes with appropriate separation of pedestrians and bicycles from motor vehicle traffic.
- All jobs should be reviewed by employers to determine if it makes sense to allow telecommuting one or more days per week.
- State extension agents (e.g., agricultural agents) should be trained in energy conservation approaches and benefits.
- Increase taxes on energy consumption that is not used for production of goods and services. This is not a blind "carbon tax", but a tax aimed at consumer level consumption.
- Recycle items as much as is worthwhile. Sometimes this can be counterproductive if there is not enough volume or recycling requires too much energy or cost.
- Conduct research on the effect of any these actions on wildlife and on human health, and on the economic vitality of our nation.
- Increase the amount of our business done electronically to minimize travel and transportation and the use of paper.

QUESTIONS FROM THE HONORABLE PATRICK KENNEDY

Regardless of whether or not we take actions to control and reduce green house gas emissions, wildlife and wildlife habitat and the ocean environment are going to change and adapt, often unpredictably, to a warming climate. Consequently, we should take steps now to develop strategies to allow for the future conservation of biodiversity and the maintenance of a healthy and resilient environment.

1. Keeping in mind that any transition to a new "Green Economy" will take decades to achieve and that most Members of Congress will want to limit unnecessary disruptions of social and economic systems, can you be more specific on what practical types of adaptive management strategies we should consider to mitigate the negative effects of climate change on our collective wildlife and ocean resources?

There are a series of steps that we should do whether or not the warming (1 deg. F) of the last 150 years continues or, having reached a peak in 1998, continues to decline, or stays at the new plateau.

I will address oceans and fisheries, because I have greater knowledge in this area. We need better information at the ecosystem level on how organisms interact with their environment. Information is most valuable if there are institutions and management mechanisms to use it. Research on improved mechanisms is needed so that fisheries can operate more efficiently with global warming, as well as in the naturally varying climate of today. There is relatively little research underway on such mechanisms. Knowledge of the reproductive strategies of many species and links between recruitment and environment is poor.

The following items are needed specifically because of climate change. Other types of research, which are prerequisites for dealing with such concerns but which support the day-to-day needs of fisheries managers or relate more to understanding how ecosystems function, are not included.

- Determine how fish adapt to natural extreme environmental changes, how fishing affects their ability to survive unfavorable conditions, and how reproduction strategies and environments are linked. Link fishery ecology and regional climate models to enable broader projections of climate-change impacts and improve fishery management strategies.
- Implement regional and multinational systems to detect and monitor climate change and its impacts—building on and integrating existing research programs. Fish can be indicators of climate change and ecological status and trends. Assemble baseline data now so comparisons can be made later.
- Develop ecological models to assess multiple impacts of human activities.
- Determine the fisheries most likely to be impacted, and develop adaptation strategies.
- Assess the potential leaching of toxic chemicals, viruses, and bacteria due to sea-level rise and how they might affect both fish and the seafood supply.
- Determine institutional changes needed to deal with a changing climate. Such changes are likely the same ones needed for mastering overfishing and coping with the variability and uncertainty of present conditions. Improved institutions would probably reduce stock variability more than climate change would increase it.
- Study the historical ability of societies to adapt their activities when their resources are impacted by climate changes.
- Research activities to better understand processes in the oceans, in particular the role of the oceans in the natural variability of the climate system at seasonal, interannual, and decadal to century timescales.
- Long-term monitoring and mapping of: water-level changes, ice coverage, and thermal expansion of the oceans; sea-surface temperature and surface air temperature; extratropical storms and tropical cyclones; changes in upwelling regimes along the coasts of California, Peru, and West Africa; UV-B radiation, particularly in polar regions, and its impact on aquatic ecosystems; regional effects on distribution of species and their sensitivity to environmental factors; changes in ocean biogeochemical cycles.
- Socioeconomic research activities to document human responses to global change

Adaptation Options

- Establish management institutions that recognize shifting distributions, abundances and accessibility, and that balance conservation with economic efficiency and stability
- Support innovation by research on management systems and aquatic ecosystems
- Expand aquaculture to increase and stabilize seafood supplies and employment, and carefully, to augment wild stocks
- Integrate fisheries and CZ management
- Monitor health problems (e.g., red tides, ciguatera, cholera)
- Coastal planners and owners of coastal properties and infrastructure should carefully consider projected relative sea level changes when evaluating new or reconstruction projects.
- Coastal planners and environmental decision-makers should consider that a healthy environment is a prerequisite for coral reefs, mangroves and sea grasses to keep pace with a rising sea and to continue their coastal protection benefits

2. Should we be doing more to re-evaluate our current policies for land use planning and public acquisition of land for wildlife habitat? Should we be adopting a broader landscape and ecosystem-based approach for protecting wildlife?

I do not feel qualified to provide guidance in this area and defer to more land-based people.

3. Finally, how might such ideas be applied to the ocean and coastal environment and the wildlife therein?

This is addressed above. In essence, we need to stop our species-by-species approach to management and embrace the ecosystem-based management concept we have been discussing for more than 30 years. In some fisheries and protected species, we are closing in on the amount and types on information necessary, but major

changes will be needed in how society and resource managers view these interactions. Not all is as it appears to be. Over fishing is blamed for problems that likely are rooted in ecosystem imbalances among species and in environmental effects that are just beginning to be understood, as was pointed out in the testimony of Dr. Gary Sharp. Further background is available at his website at http://sharpgary.org.

QUESTIONS FROM THE HONORABLE HENRY BROWN, MINORITY RANKING MEMBER

1. Do you or have you (or your organization) received any funding from the Pew Charitable Trust or the David and Lucille Packard Foundation? If so, please elaborate.

None.

2. Are you currently a party to any law suit against the Department of the Interior or the Department of Commerce (or any of the agencies within these departments)? If so, please describe

No.

QUESTIONS FROM THE HONORABLE WAYNE GILCHREST

1. If paleo-records show that corals existed in the past under high atmospheric CO_2 concentrations, why is it a problem now?

I do not believe it is a problem. I think we will run out of easily-available oil, gas, and coal before the oceans become so acidic that there is a significant problem. I understand that many of the same coral genera were present during the mid-cretaceous period when CO_2 was 2-4 times higher and coral reefs much more expansive, per the NOAA paleo website. If the corals and other animals with shells that cannot form due to high CO_2 concentrations are impeded, their ecological niche apparently becomes filled by other organisms, some with silica based shells. Things will be different, but life continues.

2. Among the various effects of climate change to wildlife and the oceans, are there issues that are more pressing than the others? Why?

For fisheries, the most important issue is the movement of centers of fisheries production to new locations, perhaps across a national border. Institutions and communities are not set up to deal with this. At present the El Niño and the Atlantic and Pacific Oscillations give us an indication of what will happen.

Also, near the top of the priorities list is a decision whether to encourage or retard opening of the Northwest passage to shipping, and secondly, how do we deal with the possible pollution effects, and the eased migration of whales and other mammals between the oceans. This Arctic ice has probably been blocking exchange for about 120,000 years. There are a myriad of important questions, such as; Do we want the gene pool refreshed in both oceans?

3. In the U.S., as plant and animal species migrate north and to higher elevations, what does that mean for the regions they leave behind? For instance, it has been said that some U.S. states that border Canada might actually benefit from the next few decades of climate change, but what will it mean for the states further to the South, and especially those on the coast?

The way to look at this is to see what happens closer to the equator. All suitable places have life and the speciation is greater there than further north. If there is food and water, all voids will be filled quickly. Warmer, wetter climates have the most diverse life. Further, within the average global temperature change, more change occurs as one moves towards the poles. The southern states will see less change. Sea level rise is also important. It has been going on since the last ice age ended just 10,000 years ago. Georges Bank, Martha's Vineyard and Nantucket were part of the mainland just a few thousand years ago. The first settlers walked there and did not need canoes. Whether or not there is any impact (acceleration) caused by human actions, it will continue until we start our slide towards the next glaciation, some 30,000 years away. During the last period between ice ages (about 125,000 years ago), the global average sea level was 13 to 20 feet (4 to 6 meters) higher than during the 20th century, and average Arctic temperatures at that time were 5.7 to 9.5 deg. F (3 to 5 deg. C) higher than present (IPCC, 2007). El Nino and other climate oscillations show us that the distribution of species and their mix changes in a few months to a year, with winners and losers everywhere, just as with the industries and communities that depend on these resources. From a practical standpoint, nearly everything in the ocean grows faster when it is warmer, as do the things they eat. Some will no longer be available nearby, and some will be

greatly reduced by interrupted feeding patterns, but they are here today, somewhere, just as they have been through countless other cycles of warming and cooling, waiting for their turn once again.

4. How do shifts in habitat range of plants and animals affect human interests such as agriculture or the spread of invasive species and diseases? How can we adaptively plan for such changes?

I am not sufficiently knowledgeable to offer advice and I defer to land-based experts.

5. The IPCC reports with 80% certainty that the changes in water temperatures, ice cover, salinity and ocean circulation are impacting the ranges and migration patterns of aquatic organisms. How will this affect management and use of these resources, and how can we prepare for any changes?

Fisheries are most affected when artificial barriers (e.g., national borders) stop pursuit by fishers in one country, causing local disruption, as centers of abundance move. Also fleets and processing plants and related infrastructure will move once it appears a change will be long-term. This is disruptive to fisheries-dependent communities. Of course, there is an equal-sized winner within the gaining group. We can prepare for this by making arrangements with neighboring countries in advance, for example by issuing individual vessel catch quotas that can be bought and sold across borders, even if the vessels are not allowed to continue fishing.

6. In the Chesapeake Bay, we are losing marshland to rising sea levels. Can you talk about what is happening to coastal wetland areas in other areas of the country and what that is doing to their ecosystems and the local economies that depend upon these natural resources?

A very high proportion of all fisheries depend on estuarine waters and marshes. Within a few months a major NOAA/NMFS report will be published describing the status of our fisheries habitats. Under preparation for several years, it is called Our Living Oceans—Habitat. Generally the coastal habitats are in good condition and major habitat loss has been greatly slowed. There are local problems, and there are sea level problems, particularly where land subsidence adds to the 2 mm/year natural rise of the sea.

7. What role do marshlands play in sequestering carbon? Is marsh restoration a viable alternative in carbon sequestration?

I have too little background to answer this question adequately, but it would be difficult to imagine a worthwhile benefit/cost ratio for a restoration project for the purpose of carbon sequestration alone. Further the reflectance of the marsh will be much lower than whatever it replaces, perhaps contributing more warming as heat sinks than reduction through CO_2 sequestration, much as trees have recently been found to do. If in doubt, walk across a marsh on a sunny day. The black and green colors absorb so much sunlight, the marsh seems like an oven.

8. The latest IPCC report warns that ocean acidification poses a threat to coral reefs and shell-forming organisms that form the base of the aquatic food chain. But the report says more study is needed to determine the full scope of the threat. What do we know about the potential impacts to U.S. coastal ecosystems today and how quickly is our understanding of acidification improving? What can Congress do to improve upon this understanding? Do we know enough to act?

As I stated above, I think this problem is overrated. However, I would support a research program that actually measures CO_2 levels and coral health on reefs (not in a laboratory. One way to look at this is by noting the rapid growth of molluscan (e.g., clams and oysters) aquaculture. These shells certainly are in good shape and forming rapidly in waters all over the globe (note that these shells nearly permanently remove CO_2 from the system). I am not aware of any incidence of failure to form shells, and I am actively involved in aquaculture consulting.

9. What additional resources or tools will the Fish and Wildlife Service and National Marine Fisheries Service need to adequately prepare and address the impacts of global warming on wildlife over the next decade?

NMFS needs to finish the recapitalization of the research fleet and get more of its scientists broadly based in species interactions and similar ecosystem level science.

10. We've heard a lot about the polar bear and the petition to list the species under the Endangered Species Act (ESA). Opponents of listing claim that the effects of global warming are in fact unclear. What evidence is there that global warming is already having a dramatic effect on the species across its range? How will an ESA listing help polar bears?

Polar bears have endured warmer periods than are forecast by IPCC, having evolved into their present form some 700,000 years ago (or 100,000 years ago) (or 200,000 years ago) (or before the beginning of the last interglacial) and their molars changed some 10,000 to 20,000 years ago. Importantly, polar bears were likely present in some final version of their present form, during the last interglacial (130-110,000 years ago) when there was virtually no ice at the North Pole and average Arctic temperatures at that time were 5.7 to 9.5 deg. F (3 to 5 deg. C) higher than present (IPCC, 2007). This date of evolution should be determined factually, as a first step, before taking action. If polar bears survived the past interglacial, the present warming may be of little consequence. In any case, the 20 polar bear populations need to be looked at individually, in terms of their threats and adaptability, and the management systems that govern their conservation.

Ms. BORDALLO. Thank you very much.

Now we will begin our questions on behalf of the Members. I would like to address my questions to Dr. Caldeira and Dr. Kleypas.

Your testimony lays out a compelling explanation of the impacts that climate change and ocean acidification are having on our ocean environment and marine resources. Some have argued, however, that because climate has changed in the past and that the oceans have experienced acidification before that there is nothing to be concerned about now.

Do you agree? If not, why do you think this is a problem now despite previous changes in the ocean environment? I would like to ask the question to both of you to get your——

Dr. CALDEIRA. Can you put my slide up?

Dr. Everett is correct that atmospheric CO_2 levels were much higher say 100 million years ago, and also the earth was much warmer, but the chemistry of the ocean is buffered by the interactions with the sediments. For example, atmospheric CO_2 today is rising 100 times faster than the rate of typical changes during the glacial and interglacial time.

To show the kind of unusual chemistry we are producing, there is a map up here produced by Dick Feely of NOAA. This red area shows where corals grow well, and the black dots there show the positions of coral reefs. The sort of orange and yellow/green color show areas where there are marginal coral reefs. A few reefs are found in those kind of color zones.

As you see, as atmospheric CO_2 levels progress through the century for business as usual scenario we get down to the map in the lower right. The predicted ocean chemistry predicts that there is no place left in the ocean with the kind of chemistry where corals are found growing today and so at least this leads some to have an expectation that corals may become extinct.

We have done modeling of the ancient past, and this kind of chemistry has not been found in the ocean for the last 55 million years almost certainly and many people think not since the time when the dinosaurs became extinct and so this kind of corrosive condition to the shells and organisms is extremely geologically unusual.

In those purple colors, the shells of some organisms will actually be dissolving. This is just very unusual when viewed from a geologic perspective.

Dr. KLEYPAS. And I would like to agree with Ken on that. In terms of the geological perspective, this is extremely unusual.

I would like to put up my first slide.

If you are not concerned about the effects on organisms, particularly calcifiers, this is a picture of a normal coral in the top and a coral that has been subjected to high PCO_2 conditions or, in other words, acidic conditions at the bottom. You can see those corals are naked at the bottom. They have completely lost their skeletons.

We suspect that this has happened in the geological past as well when there have been major CO_2 events, but, as Ken said, the last time we think that happened was 55 million years ago. So these things do happen, but these corals take a long time to recover from a process like this.

Dr. CALDEIRA. After what appears to be an ocean acidification event 65 million years ago, corals disappeared from the fossil record for two million years, and it took something like eight million years for them to fully recover, so what we are doing over the next decades has the potential to impact life in the ocean for millions of years.

Ms. BORDALLO. Thank you. Thank you very much.

I would like to ask unanimous consent that the statements of Mr. Gilchrest and the National Wildlife Federation be included for the record.

Hearing no objection, so ordered.

[The statement submitted for the record by Mr. Gilchrest follows:]

Statement submitted for the record by The Honorable Wayne T. Gilchrest, a Representative in Congress from the State of Maryland

Thank you Chairwoman Bordallo and Ranking Member Brown for the opportunity to offer testimony to the House Natural Resources Subcommittee on Fisheries, Wildlife and Oceans regarding the impacts of climate change.

The heart of my district, the Maryland 1st, is the Chesapeake Bay. The Bay is both an environmental wonder and the economic lifeblood for my constituents. We are already witnessing the impacts of climate change, and if the current trends continue, we will forever lose the Bay as we know it.

The islands of the Chesapeake are already disappearing due to rising sea levels. The Eastern shore is eroding at an accelerated rate, a fact most dramatically illustrated by the loss of historical graveyards near the water's edge. The marshes of the Chesapeake, which serve as nurseries for much of the region's wildlife, are drowning. Warmer temperatures are driving Maryland's state bird, the Baltimore oriole, north to Pennsylvania, and fewer migratory ducks are coming to the Chesapeake because of milder winter temperatures to the north. The Chesapeake's world famous crabs are under threat because the sea grasses that provide them shelter are struggling to survive in warmer waters. And the threat to the crabs of the Chesapeake, along with other crustaceans—including the plankton and krill at the foundation of the aquatic food chain—will only worsen as the oceans soak up more greenhouse gases and grow more acidic.

Climate change is rearing its ugly head in the Maryland 1st and in other coastal areas around the world, but the consequences of global warming will not stop at the shoreline—wherever that ultimately proves to be. This month's report from the Intergovernmental Panel on Climate Change (IPCC) concluded "the resilience of many ecosystems is likely to be exceeded this century" if the warming trend continues. The changes could be so widespread and take so many different forms—floods, drought, wildfires, insect infestation and ocean acidification—that between 20% and 30% of animal species assessed in the IPCC report are more likely to be threatened with extinction.

If we keep loading up the atmosphere with greenhouse gases, "there are projected to be major changes in ecosystem structure and function, species' ecological interactions, and species' geographic ranges, with predominantly negative consequences for biodiversity, and ecosystem goods and services e.g., food and water supply," the IPCC report warns. Put another way, the natural cycles that have underpinned our economy and way of life for generations could be turned upside down. Large scale and permanent disruptions to water and food supplies, together with mass migrations from coastal zones and other impacted regions, will have severe economic impacts. Fortunately, we still have time to stabilize the climate and prevent the worst impacts of global warming at a fraction of the cost of inaction.

To that end, I have joined Congressional Climate Change Caucus Co-Cchair John Olver in introducing the Climate Stewardship Act, H.R. 620. This is a companion to the bill introduced in the Senate by Senators McCain and Lieberman, S. 280. The Climate Stewardship Act is currently under consideration by this subcommittee, as well as the Energy and Commerce and Science and Technology committees.

The Climate Stewardship Act would create an economy-wide "cap-and-trade" program for greenhouse gases. Sources that annually emit more than 10,000 metric tons of carbon dioxide equivalent in the commercial, industrial, utility, and transportation sectors would receive an allocation of free credits to emit at today's levels until 2019. From today's emissions, the cap would be lowered 15% by 2020, 37% in 2030, and 75% below current emissions by 2050. Emitters would be able to bank their extra credits, borrow credits from the future, and buy and sell credits to meet their annual compliance requirements. Emitters could trade credits within their own sector or outside their sector.

To control the costs of the program—to both industry and consumers—the bill includes generous offsets. Emitters may apply these offsets toward up to 15% of their annual allowance submission requirements. These offsets include carbon sequestration (through forestry, agriculture and geologic storage), emissions reduction credits purchased from smaller noncovered sources, borrowed credits from future years' allocations, and credits purchased from EPA-approved foreign trading systems. If an entity takes accelerated action to reduce its emissions to 1990 levels by 2012, it may use offsets to meet an extra 20% of its annual compliance requirements. The bill also allows U.S. companies to fund emissions reduction projects in developing countries to earn additional credits as determined by the EPA. These credits may be traded in the U.S. or foreign market.

By establishing a cap and including offsets in the emissions trading program, the Climate Stewardship Act creates a carbon market that gives emitters a wide array of compliance options. The bill also gives these sources the opportunity to lower their emissions more quickly than the economy-wide cap and sell the surplus allowances on the carbon market, moving environmental compliance from the expense line to the revenue line of the balance sheet. The potential to profit from emissions reductions will spur investment in clean energy technologies, creating new jobs and developing a new generation of industrial, commercial and consumer products that can be sold on the export market. In this way, the Climate Stewardship Act lowers greenhouse gas emissions in a way that minimizes compliance costs, while at the same time generating new opportunities for business, industry and the American worker.

The Climate Stewardship Act also stipulates that a portion of the proceeds from buying and selling credits in the emissions market will be directed to state agencies to protect species that are struggling to cope with climate change. States bear the largest burden for the conservation of fish and wildlife species. Using both state and federal resources, they work to keep as many species as possible off the endangered list through the implementation of the State Wildlife Diversity Plans, which are approved by the U.S. Department of the Interior. The Climate Stewardship Act will provide the states with a new source of funding to mitigate the impacts of climate change on fish and wildlife diversity wherever possible.

Again, I thank Chairwoman Bordallo and Ranking Member Brown for investigating the impacts of climate change on wildlife and oceans. This country rose from humble beginnings to international economic supremacy because it was blessed with tremendous natural resources. But we have been slow to recognize that the climate—like an oil field, coal seam, hardwood forest or fishing ground—is a natural resource too. If the U.S. and other nations continue to jeopardize that resource through the excessive burning of fossil fuels, they will undermine the very foundations of the world economy. Our way of life and our wealth as a nation have depended upon a stable climate, and our economy can no longer ignore this fundamental truth.

[The statement submitted for the record by The Nature Conservancy follows:]

Statement submitted for the record by The Nature Conservancy

Summary

On behalf of its one million members, The Nature Conservancy appreciates the opportunity to submit for the record this testimony on "Wildlife and Oceans in a Changing Climate." Climate change is perhaps the greatest long-term threat to healthy ecosystems that can support people and wildlife. Prompt action to address this threat is critical to minimize future harm to nature and to the social and economic fabric of our global society.

Higher temperatures, changes in precipitation patterns, and other consequences of climate change could have serious impacts on human communities and ecosystems around the world. Wildlife and ecosystems are particularly vulnerable because they have a limited ability to adapt to the fast rates and the magnitude of the potential changes projected under future climate change scenarios. In the United States, wildlife and ecosystems that are especially threatened by a changing climate include:

- Ecosystems and species that only exist at high latitudes or elevations, and will be pushed to extinction as habitats shift pole-ward or upslope following suitable temperatures.
- Migratory waterfowl that depend on the North American prairie pothole region as a critical breeding ground
- Trout and salmon that thrive in cold freshwater systems
- Coastal ecosystems vulnerable to sea level rise and increased storm damage
- Coral reef ecosystems that are threatened by acidification and warming of the oceans.

The Nature Conservancy is working to monitor these and other climate change impacts around the world. With a growing understanding of present and future scenarios, the Conservancy will be better equipped to help ecosystems cope with warming, changes in precipitation, and other impacts of climate change.

Nevertheless, strong action to address the causes of climate change will be essential. The Nature Conservancy is calling for legislation and policies that include three paramount concepts:

- A strong cost-effective cap on emissions and a well-designed market-based program designed to stabilize atmospheric greenhouse gas concentrations at a level that ensures the well being of human communities and ecosystems worldwide.
- Reduction of emissions from forest and land use practices through the incorporation of a credible offsets program.
- Support for adaptation programs that are designed to help ecosystems and the human communities who rely on them to cope with the impacts of climate change.

We discuss these issues further in the testimony that follows.

Climate Impacts on Wildlife and Oceans

Consequences of climate change, such as increasing temperatures, changes in precipitation patterns, and higher atmospheric carbon dioxide concentrations could have serious impacts on human communities and ecosystems around the world. The environment is particularly vulnerable because it has a limited ability to adapt to the fast rates and the magnitude of potential changes projected under future climate change scenarios. The National Assessment Synthesis Team of the U.S. Global Change Research Program published a report in 2000 that examined climate change and variability in the United States, with a focus on specific regions and sectors including human health, water resources, forests, coastal areas and agriculture. The report found that all natural ecosystems in the United States, including wetlands, forests, grasslands, rivers, and lakes are at risk. Some ecosystems, such as alpine meadows, coastal wetlands, and certain forest types could disappear altogether. Conservation groups such as The Nature Conservancy are already taking steps to understand these changes and help ecosystems adapt to them. However, a stabilization of atmospheric greenhouse gas levels is necessary to ensure that the world's biodiversity is protected.

The Summary for Policymakers of the Working Group II Contribution to the Intergovernmental Panel on Climate Change's (IPCC) Fourth Assessment Report released in April 2007, further advances the current scientific knowledge related to

the impending threats that wildlife will face as a result of climate change.[1] These changes may undermine some of the conservation work that the government and the conservation community has accomplished to date, and will likely change the species composition within local land trust preserves, Conservancy preserves, and even our national parks.

Wildlife

Impacts of climate change are already having a noticeable effect on wildlife in the United States. For example, changes in temperature and precipitation are already driving vegetation and ecosystems around the globe toward cooler polar areas and up mountain slopes. Some species and communities, such as polar bears or alpine meadows, may be left without any remaining viable habitat and therefore driven to extinction. In addition, such shifts in range could be impeded by natural and manmade physical barriers, thereby preventing some species and ecosystems from following their ideal climate conditions. Increases in freshwater temperatures will alter water quantity and quality, affecting a variety of freshwater fish populations, especially salmon and brook trout. In the Midwest, prairie wetland habitats that are critical breeding grounds for ducks and other migratory waterfowl are expected to dry up and disappear as a result of vegetation shifts and drought conditions.[2]

Impacts on Freshwater Fish: Higher temperatures and intensified human land use could cause stream temperatures to increase by as much as 5 δ Fahrenheit by 2100. Concurrently, changes in seasonality and precipitation patterns could significantly alter stream flows. Trout and salmon that thrive under cold water conditions are projected to experience significant declines in population. A 2002 study concluded that by the end of this century as much as 40 percent of current trout and salmon habitats could be unsuitable for these species.[3]

Impacts on Migratory Waterfowl: Climate change impacts could cause a significant reduction in populations of migratory waterfowl all across the United States due to a reduced availability of suitable breeding habitat. The prairie pothole region of north-central United States is the single most important breeding ground for North American migratory waterfowl. Higher temperatures and decreased precipitation caused by climate change could lead to a significant reduction of wetlands in the area, which would translate to a decrease in the number of breeding waterfowl by as much as 69 percent. On the east coast, rising sea levels could also flood many coastal salt-water wetlands, significantly reducing suitable winter waterfowl habitat.[4]

Oceans

Any change in the climate also affects the physical and biogeochemical characteristics of the world's oceans. Oceans have been absorbing an estimated 80 percent of the heat added to the climate system, and studies have documented a rise in average global sea temperature to depths of up to 3000 meters. Higher sea surface temperatures are already having an impact on oceanic ecosystems. Over the past decade, scientists have observed an increase in the frequency and severity of coral bleaching events. Scientists project that these events will only become more common as temperatures rise, which would place serious strain on these already fragile coral reef ecosystems.

This temperature rise has also caused thermal expansion of the seawater, which combined with the melting polar ice caps has led to a rise in sea levels.[5] The rate of sea level rise has markedly increased in recent years to an average of about 3.1 mm per year from 1993 to 2003. Conservative estimates project that sea-levels could rise between 0.18 and 0.59 m by the end of this century.[6] Sea-level rise will have serious impacts on the United States' already threatened coastal ecosystems. Prevented by coastal development and infrastructure from shifting inland in response to sea level rise, in many areas these valuable ecosystems could disappear. The loss

[1] Intergovernmental Panel on Climate Change (2007). Climate Change 2007: The Physical Science Basis. Summary for Policymakers of the Fourth Assessment Report. IPCC Secretariat, Switzerland.

[2] National Assessment Synthesis Team (2000). Climate Change Impacts on the United States. The Potential Consequences of Climate Variability and Change. Overview. Cambridge University Press, USA.

[3] O'Neal, K. 2002. Effects of global warming on trout and salmon in U.S. streams. Defenders of Wildlife, Washington, DC,

[4] Inley, D.B., et al. 2004. Global climate change and wildlife in North America. Wildlife Society Technical Review 04-2. The Wildlife Society, Bethesda, Maryland, USA. 26 pp.

[5] Intergovernmental Panel on Climate Change (2007). Climate Change 2007: The Physical Science Basis. Summary for Policymakers of the Fourth Assessment Report. IPCC Secretariat, Switzerland.

[6] ibid

of beaches, wetlands, and other coastal ecosystems would have serious implications for the wide variety organisms that depend on the integrity of these ecosystems as breeding or feeding grounds. For example, nesting opportunities for sea turtles will decrease as beaches are flooded or eroded. Mangrove forests will be impacted by coastal erosion, salt-water inundation, and an increase in the intensity and frequency of storm surges, and in many areas could disappear.

Impacts on Corals: Coral reefs are the center of tropical marine biodiversity, providing habitat and breeding grounds for thousands of species of fish and marine organisms. Many corals exist under conditions that are already close to their upper temperature tolerance limits. When sea surface temperatures exceed this maximum limit, corals may bleach due to the loss of the symbiotic algae that provide the coral with nutrients. Although local bleaching events do occur naturally, corals need at least an estimated ten years to fully recover. However, scientists have already observed an increase in the frequency and severity of coal bleaching events. As sea surface temperatures continue to rise, mass coral bleaching events are projected to increase, causing widespread coral mortality. In addition, increased atmospheric carbon dioxide levels lead to a rise in oceanic acidification, which could result in weaker coral skeleton frames, reduced growth rate, and increased susceptibility to breakage and bio-erosion. [7] All together, these impacts from climate change make coral reefs one of the most threatened ecosystems from climate change.

Impacts to Turtles: Sea-level rise due to climate change could cause flooding and erosion of sea turtle nesting beaches. Turtle nesting beaches that are backed by development or steep topography will be unable to shift inland as sea levels rise and could disappear, leaving female sea turtles with fewer suitable nesting sites. Increased temperatures and changes in seasonality will also alter the nesting habits of females and could alter the sex ratio of turtle hatchlings. Scientists have already observed a trend of earlier nesting dates for the loggerhead sea turtle on the Atlantic coast of Florida. [8] Incubation temperature of eggs co-determines the sex of hatchlings, and therefore higher temperatures could skew the sex ratio towards a predominance of female hatchlings. [9] [10]

Impacts on Mangroves: Sea level rise is the most significant climate change threat to mangrove forests and other coastal wetlands. Even a small rise in sea level could result in erosion, flooding, and salt-water inundation of these ecosystems. Mangrove ecosystems that are backed by salt flats and low-lying coastal flats will have greater inputs of sediments and silt from both land and sea and have the space to shift inland as the sea-level rises. However, many mangrove forests are backed by coastal development and infrastructure or other physical barriers. These mangroves have nowhere to move and limited sources of sediment on which to build, which means these ecosystems are especially vulnerable to a shrinking habitat caused by sea level rise.

As these examples highlight, the effects of climate change on wildlife, oceans, human communities and ecosystems could be profound. In order to avert the extreme effects of climate change, a two pronged approach of adaptation and mitigation is necessary.

The Nature Conservancy's Climate Monitoring and Adaptation Work

In order to better understand climate change and how wildlife and ecosystems may adapt, scientists at The Nature Conservancy are actively monitoring these and other climate change impacts around the world. With a growing understanding of present and future scenarios, the Conservancy will be better equipped to help ecosystems cope with warming, changes in precipitation, and other impacts of climate change.

For example, the Conservancy is taking a specific look at the changing climate in the Sierra Nevada Mountains of California. Research is underway in an old-growth forest area to monitor climate change impacts and to develop strategies for

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[7] C. Langdon, 2003, Review of Experimental Evidence for Effects of CO_2 on Calcification of Reef Builders, Proceedings of the 9th International Coral Reef Symposium, Bali, Indonesia, 23-27 October 2000, Vol.2, pp. 1091-1098.

[8] R.R. Carthy, A.M. Foley, Y. Matsuzawa, 2003, Incubation Environment of Loggerhead Turtle Nests: Effects on Hatching Success and Hatchling Characteristics, in Loggerhead Sea Turtles, A.B. Bolten and B.E. Witherington, (eds.), pp. 144-153, Smithsonian Institution, Washington, DC, USA.

[9] R.R. Carthy, A.M. Foley, Y. Matsuzawa, 2003, Incubation Environment of Loggerhead Turtle Nests: Effects on Hatching Success and Hatchling Characteristics, in Loggerhead Sea Turtles, A.B. Bolten and B.E. Witherington, (eds.), pp. 144-153, Smithsonian Institution, Washington, DC, USA.

[10] F.J. Janzen, 1994, Climate Change and Temperature-Dependent Sex Determination in Reptiles, Proc. Nat. Acad. Sci., 91, pp. 7487-7490.

conserving these unique natural communities. On the coastal plain of Alaska, as in many high latitude circumpolar regions, shrubs and other woody vegetation are invading the arctic tundra. The Alaska chapter of The Nature Conservancy is working closely with state and federal agencies to monitor the changes and identify ways to preserve these unique tundra ecosystems.

Scientists with The Nature Conservancy's Global Climate Change Initiative are also documenting changes outside of the United States. For example, in the mountains of Yunnan in China, Conservancy scientists are monitoring the changes occurring in alpine tundra ecosystems and simulating the interaction between climate change and human impacts in these mountain areas. Scientists are also collaborating with university researchers to document global vegetation shifts. Conservancy scientists have already observed significant vegetation shifts in some areas, such as woodlands giving way to grasslands in Africa and alpine meadows giving way to forests in California.

Through monitoring and analyzing these shifts, the Conservancy can prioritize areas for conservation and develop natural resource management practices that maintain and improve the function of these ecosystems. Strategies developed at one project site can be applied to similar ecosystems elsewhere around the world:

- Through the establishment of oceanic research stations such the Palmyra Research station 1,000 miles south of Hawaii, the Conservancy is leading a global effort to identify species of coral that are resilient to warmer temperatures and bleaching events. With this information, the Conservancy can work to ensure these "survivors" are protected through effectively managed, large-scale marine protected area networks worldwide. In addition, scientists have expanded their work on resilience in the face of elevated temperatures to address change in acidity. These results are providing some hope of adaptation options for coral reefs around the world.
- In the Albemarle Sound of North Carolina, the Conservancy is developing potential restoration projects that would help protect the shoreline from increased erosion and inundation caused by rising sea levels. These projects include planting native cypress forests, restoring submerged aquatic vegetation beds, establishing reefs to block storm surges, and planting brackish marsh grasses on shore lands that are likely to be submerged. This work is now being applied to other vulnerable coastal areas along the United States' eastern coast and into Central America.
- In New Mexico, the Conservancy is conducting a statewide analysis to identify places, species, systems and other natural resources at risk due to climate change. The study will also propose measures that land and water managers can take to abate threats to plants, animals and natural processes as the impacts of climate change continue to grow.

Climate change will alter landscapes and seascapes as we know them. Projects such as those listed above will help us analyze the impacts of climate change on plants, animals and natural communities. These projects will also help to create innovative conservation solutions that will enable natural areas to cope with and adapt to what may be the unavoidable effects of climate change. However, this work does not abrogate the need for climate change mitigation; reducing carbon emissions now can avert the extreme impacts of climate change.

Mandatory U.S. Climate Change Program Needed

The Nature Conservancy strongly supports the adoption of a cost-effective mandatory cap and trade program to limit greenhouse gas emissions in the United States. Significant reductions in emissions will be needed to mitigate the future impacts of climate change. As the leading emitter, the United States should lead with domestic reductions, which will also provide a platform for a more effective international climate protection regime.

A well-designed program should not harm the economy or hurt the competitive status of U.S. industry. Such a program would unleash and set in motion available low-cost opportunities to reduce U.S. emissions. Many steps, for example stimulating improvements in energy efficiency, could be taken immediately that would likely benefit the U.S. economy.

A comprehensive domestic program to address climate change must include three paramount concepts:

- **A strong cost-effective cap and well-designed program to protect ecosystems and human well-being.** The core function of a climate change policy should be to set in motion and sustain a course of long-term reductions in greenhouse gas emissions that will be sufficient to stabilize atmospheric greenhouse gases at a level that will protect human society and the natural world. A program should be designed to be cost-effective and to send appropriate long-

term price signals to stimulate needed investment in emissions-reducing technologies. The level of a domestic cap should be sufficient to represent an appropriate U.S. contribution to global emissions reductions, given the urgent need to stabilize the atmosphere at a carbon dioxide-equivalent concentration that will protect ecosystems and human well-being.

- **Reduction of emissions from forest and land use through the incorporation of a robust and credible offset program.** The Nature Conservancy strongly supports the inclusion of robust offset provisions in a greenhouse gas cap and trade program that will allow real, additional, verifiable, permanent and enforceable offsets from domestic and international activities to be used by regulated entities for compliance with their allowance obligations. Offsets offer real cost-effective emission reductions and lower the cost of emission reduction programs, thereby increasing the flexibility of the program and allowing for the setting of lower emissions targets. Offsets from land conservation and restoration projects can provide additional benefits by supporting forest protection and protection of other natural areas. International offsets from this sector are particularly important because land use and deforestation represent a third of developing country emissions and efforts to reduce these emissions contribute greatly to poverty reduction and biodiversity conservation. Proven methods for reliably measuring, monitoring and verifying land-based carbon offsets already exist and are in widespread use.
- **Assurance that the program helps the natural world and those who depend on healthy ecosystems adapt to the impacts of climate change.** Climate change is already creating challenges to vulnerable species and habitats in the U.S. and around the world. Climate change legislation that uses auctions to distribute allowances that would be used to comply with a cap on greenhouse gas emissions would be of critical assistance to addressing these challenges. The Nature Conservancy supports a program that will transition to a full auction of allowances as quickly as feasible and economically desirable, considering an interest in maintaining market stability and gaining experience with the auction mechanism. The Conservancy advocates dedicating at least 25 percent of auction revenues to a Climate Change Adaptation Fund that would assist the natural world in adapting to the impacts of climate change in the U.S. and abroad, and help reduce the impacts of climate change on the most vulnerable members of society.

In addition, supplementary policies such as fuel economy, energy efficiency, green building standards, funding for research and development into advanced technologies, and consumer incentives to facilitate GHG reductions will be needed to ensure that cost-effective opportunities to reduce emissions are not passed up because of market failures or other obstacles.

Climate Change Adaptation Fund

As the climate begins to change, the need for efforts to support climate change adaptation is already great. The Conservancy believes strongly that a significant fraction—at least 25 percent—of the revenues from an auction of allowances under a mandatory cap-and-trade carbon system should be dedicated to a climate change adaptation fund that will include funding to assist domestic and international wildlife and ecosystems in adapting to a changing climate regime.

Changes to the natural world around us have serious implications for plant and animal life, but also for people. People depend on nature in myriad ways. Fisheries, timber harvests, grazing, and protected areas are all managed based on ecological processes that are being fundamentally altered as a result of climate change. If we are not proactive and do not anticipate the changing world, many sectors of our society will suffer severely. We must fund activities aimed at developing and implementing successful adaptation strategies to protect our investments in natural assets and nature reserves in response to climate impacts that are already detectable in natural systems and in many plant and animal populations. Also particularly vulnerable are people who depend most significantly on the natural world.

In the face of this threat, there is a need for federal attention to programs to address these changes. Within the Climate Change Adaptation Fund, the Conservancy recommends that at least 10 percent of the auction revenues be dedicated to state and federal efforts to protect natural systems in the U.S. and help them adapt to climate change. The Conservancy recommends that the remaining revenues in the Climate Change Adaptation Fund be dedicated to protecting ecosystems in other countries and helping vulnerable Americans adapt to climate change. We discuss our recommendations in more detail below.

Adaptation Assistance for U.S. Fish and Wildlife and Ecosystems

The Conservancy supports a policy approach that would set aside at least 10 percent of the allowance pool revenues to fund actions within the U.S. to facilitate adaptation of fish and wildlife species and habitat to climate change. Thirty percent of these funds should be allocated to the Department of the Interior to fund federal programs. Given that approximately 30 percent of lands in the U.S. are under federal ownership and management, investing in federal adaptation programs is a high-leverage approach to minimizing climate change damages to natural resources. Climate change is already affecting the ability of federal natural resource management agencies to protect the investments that American taxpayers have made in protecting land and water resources. For example, agencies that manage our federal forestlands are already faced with the challenges of protecting against higher risks of forest fire, pest outbreaks (e.g., the pine beetle infestation threatening forests in the northern U.S. and Canada), and loss of tree species linked to climate change. Providing these agencies with resources to adapt to climate change in the near term will reduce the risk of catastrophic impacts to important land and water resources. In addition, acting now to minimize the impacts of climate change would be far more cost-effective than working to recover these resources after the damages had already occurred. To protect wildlife and natural resources in the U.S., the Conservancy believes that a significant fraction of the adaptation funding should be dispersed to federal agencies that manage land and water resources, for example the Bureau of Land Management, the Forest Service, the Fish and Wildlife Service, the U.S. Geological Survey, the U.S. Department of Commerce, the Natural Resources Conservation Service, the Army Corps of Engineers, and others for the following general purposes:

- to protect natural communities that are most vulnerable to climate change;
- to restore and protect natural resources that directly guard against damages from climate change events; and
- to restore and protect ecosystem services that are most vulnerable to climate change.

This could include:

1) Federal programs and projects that will: identify Federal lands and waters that are at greatest risk of being damaged or depleted by climate change; monitor Federal lands and waters to allow for early detection of impacts; develop adaptation strategies to minimize the damage; and restore and protect Federal lands and waters at the greatest risk of being damaged or depleted by climate change;
2) Federal programs and projects to identify climate change risks and develop adaptation strategies for natural grassland, wetlands, migratory corridors, and other habitats vulnerable to climate change on private land enrolled in the Wetlands Reserve Program, the Grassland Reserve Program, or the Wildlife Habitat Incentive Program;
3) Programs and projects under the North American Wetlands Conservation Act and the Neotropical Migratory Bird Conservation Act to protect habitat for migratory birds that are vulnerable to climate change impacts;
4) Programs and projects that will: identify coastal and marine resources (such as coastal wetlands, coral reefs, submerged aquatic vegetation, shellfish beds, and other coastal or marine ecosystems) at the greatest risk of being damaged by climate change; monitor those resources to allow for early detection of impacts; develop adaptation strategies; protect and restore those resources; and integrate climate change adaptation requirements into State plans developed under the coastal zone management program established under the Coastal Zone Management Act of 1972, the National Estuary Program, the Coastal and Estuarine Land Conservation Program, or other comparable State programs;
5) Programs and projects that will conserve habitat for endangered species and species of conservation concern that are vulnerable to the impact of climate change;
6) Federal Land and Water Conservation Fund projects;
7) Programs and projects under the Forest Legacy Program that will support State efforts to protect environmentally sensitive forest land through conservation easements to provide refuges for wildlife;
8) Other Federal or State programs and projects identified as high priorities for the general purposes listed above;
9) Efforts to address climate change in Federal land use planning and plan implementation and to integrate climate change adaptation strategies into comprehensive conservation plans prepared under section 4(e) of the National Wildlife Refuge System Administration Act of 1966; General Management

Plans for units of the National Park System; Resource Management Plans of the Bureau of Land Management; and Land and Resource Management Plans under the Forest and Rangeland Renewable Resources Planning Act of 1974 and the National Forest Management Act of 1976; and

10) Projects that will promote sharing of information on climate change wildlife impacts and mitigation strategies across agencies, including funding efforts to strengthen and restore habitat that improves the ability of fish and wildlife to adapt successfully to climate change through the Wildlife Conservation and Restoration Account established by section 3(a)(2) of the Pittman-Robertson Wildlife Restoration Act.

The remainder of the 10 percent of allowance pool revenues set aside for domestic fish and wildlife and habitat adaptation would go to state programs administered under the Pittman-Robertson State Wildlife Grant program. This money would be used in accordance with state comprehensive wildlife conservation strategies to undertake the following activities:

- develop relevant information, conduct research, and undertake monitoring to improve the ability of fish and wildlife to adapt and respond to the impacts of climate change;
- develop and conduct projects to address observed or anticipated effects of climate change on fish and wildlife species and populations; and
- implement actions to manage, conserve, and restore fish and wildlife habitat to improve the ability of fish and wildlife to adapt and respond to the impacts of climate change.

Given that approximately 9 percent of lands in the U.S. are owned and managed by state governments, investing in state adaptation programs is also a relatively high-leverage approach to addressing climate change impacts to natural resources.

Adaptation assistance for ecosystems abroad

The Conservancy also supports the use of allowance revenues to fund international conservation activities that will protect globally significant species and habitats from the effects of climate change. We are working with other international conservation organizations to develop common recommendations for policy makers about how an international adaptation program could be structured. We look forward to sharing these recommendations as soon as possible.

Such international funding should be incremental to the 10 percent of allowance revenue that we recommend be dedicated to assist domestic wildlife and habitats with adaptation to an altered climate.

Adaptation for affected populations

The Conservancy also recommends that a portion of revenues in the Climate Change Adaptation Fund be dedicated to assist vulnerable human populations in responding to the impacts of climate change.

Other uses of revenues

Beyond funding to facilitate adaptation of fish and wildlife, the remaining funds in the Climate Change Adaptation Fund could be used:

- To assist low-income consumers as part of the strategy to address climate change. For example, this could include additional funding to the Low Income Home Energy Assistance Program and other efforts to reduce energy costs for these vulnerable Americans.
- To assist displaced workers with transitional assistance, including assistance with transition to new employment where jobs are displaced as a consequence of a restructuring of the economy toward lower greenhouse gas emissions.

In addition to funding activities to facilitate adaptation to climate change, some portion of the revenues from allowance auctions should be invested in a Clean Energy Fund to support research on and development and deployment of emissions reductions technologies. Revenues from an auction could also be used to offset payroll or other taxes as a further means of offsetting any distributional effects of increased energy prices.

Conclusion

The Nature Conservancy appreciates the opportunity to present our views to the Subcommittee on this timely and critical topic. We would be pleased to work with you in answering questions you may have or in crafting legislation to address the issues identified in our testimony.

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Ms. BORDALLO. And now I would like to recognize the acting Ranking Member, Mr. Sali, for any questions.

Mr. SALI. Thank you, Madam Chair.

For Dr. Caldeira and Dr. Kleypas, you are both concerned about acidification, and I am curious. If I understand, Dr. Caldeira, your explanation, the CO_2, something happens when it gets into the ocean water and then it turns to carbonic acid. Am I correct?

Can you give me just a little explanation about that?

Dr. CALDEIRA. Sure. Without going into too detailed a chemistry lesson here, the carbon dioxide is CO_2. Water is H_2O. They join together, and then when they join together protons start coming off or hydrogen ions so that this hydrogen ion attacks the carbonate ion.

Corals make their skeletons out of calcium carbonate, so there is calcium and carbonate. The hydrogen ion that is produced when the CO_2 reacts with seawater reacts with this building block and removes one of the building blocks that corals and many other organisms need to build their shells and skeletons.

The issue is if the carbon dioxide is released to the environment very slowly from like it is from volcanos then there is a chance to react with the various rocks and sediments on the earth's surface, and this neutralizes this acidity. We are emitting the carbon dioxide so rapidly that these buffering processes don't have a chance to react.

I can say that the chemistry part of this is very well understood. You know, I think where there is uncertainty is on what is the biological response. You know, the experiments have been done in university laboratories for the most part or NOAA laboratories and on a few individuals in sort of fish tanks or isolated situations and so we are not sure exactly what the real impacts will be in real ecosystems, but the laboratory experiments give plenty of cause for concern.

Mr. SALI. Well, I guess I am trying to figure out. Do the plants in the ocean use photosynthesis type processes to grow, correct, and so my question is how is it that the carbon dioxide is not used by those plants to grow, and how does it end up turning into carbonic acid?

Dr. KLEYPAS. Well, first of all, as Ken said, the carbonic acid is what causes the pH to drop in the oceans, which is the term we call ocean acidification.

In terms of plants in the ocean, most of the plants in the ocean by far are marine algae. Marine algae don't use CO_2 the way that land plants use CO_2 so there is not much of an opportunity for fertilization because the increase in carbon dioxide in the ocean is quite small, and it doesn't help these organisms, particularly given in the light that they are also limited by nutrients in the ocean.

Mr. SALI. I am going to expose just a little level of lack of knowledge here.

Dr. KLEYPAS. OK.

Mr. SALI. Am I correct that corals typically grow in fairly shallow water?

Dr. KLEYPAS. Corals grow in shallow water, and they are——

Mr. SALI. And most of the plants that live in shallow water would use the photosynthesis process now?

Dr. KLEYPAS. They do photosynthesize. The algae photosynthesize.

Mr. SALI. How does the carbon dioxide know whether it is going to be plant food, if you will, or if it is going to be carbonic acid.

Dr. KLEYPAS. Actually that is a really good question. The CO_2, once it is in the water as carbonic acid, it actually breaks apart fairly rapidly to something we call bicarbonate and carbonate.

Most plants use bicarbonate in the ocean, and it is very, very abundant. They also have something called a carbon concentrating mechanism. That allows them to store a lot of——

Mr. SALI. But how does the carbon dioxide decide what it is going to be in its future life?

Dr. KLEYPAS. The plants take up bicarbonate to photosynthesize, and the CO_2 just changes the pH of the ocean.

Do you want to add something to that, Ken?

Dr. CALDEIRA. Yes. I mean, there have been experiments done. You know, not every kind of organism builds a shell out of calcium carbonate, and there have been experiments where you basically take a bucket of water and give all the phosphorous and nitrogen and all the other nutrients that the plants want.

In these experiments, if you give added carbon dioxide some plankton can actually grow more rapidly so there is some potential in these kind of situations for increased growth, but in the real ocean plankton are typically limited by not having enough fertilizer, not having enough phosphorous or nitrogen.

It is not really the carbon dioxide deciding what it is going to do. It dissolves in the water, and if it happens to be against a coral reef it inhibits the coral from building its shell or skeleton. If it happens to go up against a plankton it makes it a little easier for plankton to get its carbon.

You know, wherever there is light and there is nutrients things will grow in the ocean, so I don't want to overstate this, but nobody is saying that there will be less photosynthesis in the ocean.

What we are saying is that key ecosystems are threatened, such as corals, and that other ecosystems may also be threatened, but really the studies haven't been done to identify the extent of threat to fisheries and other kinds of important resources.

Mr. SALI. So would it be fair to say that probably we need more information before we take action?

Dr. CALDEIRA. I think we have enough information to take action, but we certainly need more information.

I think there is enough information to be alarmed and to start working on energy systems that reduce our carbon dioxide emissions, but along with that we need to study what the possible effects on other ecosystems are.

Also, we can assume that climate change and ocean acidification will stress ecosystems, and we need to reduce other stresses such as loss of the wetlands and the overfishing and so anything we can do to reduce stresses on ecosystems will help.

I think there are three things: Reduce emissions, study the systems and reduce other stresses on the ecosystems.

Mr. SALI. Madam Chairman, if I could just wrap up real quickly?

Ms. BORDALLO. Yes.

Mr. SALI. Dr. Sharp and Dr. Everett, would you agree with that conclusion that way, or do you think we need more information before we take action?

Dr. SHARP. I spent a good bit of time traveling the world, and one of the first things you discover is those islands that have pristine corals don't have any people, and where you find most of the coral bleaching phenomena is usually with a very high population level, so there is what I call a hormetic effect, an additional problem that comes from the stuff that we leak out into the ocean around.

There is a wonderful example of exactly how this works in the Caribbean. If you go to the Isle Roatan on the east coast of Honduras, they actually if you want to go swimming there they will show you what happened when they developed and where all the hog pens are and things with dead coral everywhere.

If you go to the other side where there are no people, they will train you to make sure that you don't touch things. They will show you a handprint that was put there 10 years ago. It is a dead hole. Meanwhile, around there is basically pristine coral. That is a lesson in life that most people who sit in a laboratory never quite figure out.

The other big picture thing, of course, the conversion from the last ice age to present. The entire Barrier Reef was above sea level. When you think about 1.8 to two millimeters sea level rise per year over 20,000 years, you end up with the Great Barrier Reef. It is an interesting phenomenon.

It also has a north/south distribution. It is very healthy in the warmest section of the warm pool and is actually the scariest down near agriculture and other things on the north coast of Australia, so there is a lot more to worry about than CO_2.

Doubling the pH by—I am sorry. Doubling the pH is the wrong word. Raising the pH level or decreasing the pH level by a tenth of a unit is more than doubling the CO_2 component in the atmosphere. A tenth of a unit.

pH is a logarithmic function. If we wanted to bring the ocean water of pH 8.2 down to 7.0 it would take 48 times as much CO_2 in the atmosphere as there exists today. You can kind of whittle your way down that if you want to figure out what it means to go from 7.8 to 7.75.

We don't have a tool that measures pH to three decimal points. It just doesn't exist.

Dr. EVERETT. I would just like to add that I agree with Ken on taking prudent actions essentially and reducing emissions where it makes sense to do so, but not strapping our economy unless our competitors do the same and then working to do the science so we learn how all these critters work together out there and what in fact the level, the impact of additional CO_2 in the water is.

Part of this, I am just reminded by my Russian colleagues that always say look at what happened in the past before you think about what is going to happen in the future. We just need to make

sure that when let us say if the acidification does come to take place that the critters that come with it are along the lines that we can deal with. We know that things are going to change. Some go up. Some go down in all of this. Acidification is one of those examples.

In the Mid-Cretaceous, in the age of the dinosaurs, the corals were much further away from the equator. According to a NOAA site, it looks like they were doing fine. It talks in terms of the expansiveness of the corals when the atmosphere was two to four times the level of CO_2 in it.

Mr. SALI. Thank you, Madam Chairman.

Ms. BORDALLO. Thank you. Thank you.

Before we wrap up the hearing this morning—I guess it is still morning—Dr. Eakin, in your testimony you mentioned that the *Reef Manager's Guide* provides information on the causes and the consequences of coral bleaching and management strategies to help local and regional reef managers reduce this threat to coral reef ecosystems.

Can you elaborate on some of these strategies to protect coral reefs from local stressors and manage reef ecosystems with rising temperatures in ocean acidification in mind?

Dr. EAKIN. Thank you for that question. I agree very much with something that Dr. Sharp was saying a moment ago. The combination of different stressors on environments such as coral reefs is extremely important, and what we need to do is look at this holistically, taking into consideration all of the various forms of stress.

We know that the oceans are warming, and we have seen what is happening in terms of the oceans acidifying. We don't anticipate that these stresses are going to be going away in the immediate future, so that means that we need to do all that we can from a resource management perspective to reduce those other stresses that also threaten the reefs.

All of these, whether it is warming, whether it is acidification, whether it is pollutants, whether it is sediments, whether it is overfishing or excess use by tourism, these are all impacts that are very important and work together.

So what we need to do is put greater information in the hands of managers so that they can work in their area of control to reduce those other local areas of stress, making it easier for corals to potentially survive through these other large-scale stresses over which they don't have any control.

If I might comment on one thing very briefly along these lines, the changes that we are seeing currently are large ones, whether it is from local stress from global populations or whether it is the climate scale changes that we are seeing.

As Dr. Caldeira said, when we had that change in ocean pH 55 million years ago, it took millions of years to recover.

At a meeting about 10 years ago, a geologist named Gary Molter made a great statement regarding what was going on at that time in the early stages of coral bleaching that was being seen. His statement was while I don't question that corals as organisms will survive, I cannot afford to stand back while these resources, these ecosystems, are changed throughout my lifetime, that of my children and their children.

Ms. BORDALLO. Thank you. Thank you very much.

Just as a final question to anyone on the panel that wishes to answer it, if we act now to reduce carbon emissions, how quickly will we see positive change in the oceans, and how much would we need to reduce them to see this change?

Conversely, if we do nothing for another 10 years, how long would recovery take?

Dr. CALDEIRA. If carbon dioxide emissions were to cease today, which is of course unrealistic, the ocean acidification problem would get better right away. The earth would continue to warm and then would get——

Ms. BORDALLO. Excuse me. I didn't say cease to exist, but I said reduce.

Dr. CALDEIRA. OK. Yes. You know, one of the things, the studies have not really been done to exactly determine how much you would need to reduce to achieve different thresholds.

I have done some preliminary calculations that suggest that the kind of numbers that have been bandied about—about say 80 percent by 2050 would be the level of effort required.

I just want to take this opportunity to make one additional point. One thing is that when planning for protection of wetlands and other resources, it is important to take sea level rise into account and so it would be good, for example, if planning for future wetland protection would assume that sea level might be a meter higher in the future and that that higher sea level be taken into account in future planning.

Ms. BORDALLO. Thank you very much.

Do any other of the witnesses have any comments? Yes, Dr. Sharp?

Dr. SHARP. I would like to make it rather clear to everyone, I think we all agree that there are problems that need solved. That has not ever been the big problem.

John Everett, when he was working for NOAA, was given the responsibility back in 1986 and 1987 of putting together the first ecosystem base management system for NOAA. I was contracted to get out and work with the people in the field and try to find all the expertise we could throughout the NOAA and other institutional systems.

We put that project together, and it didn't start in the ocean. It started in the highlands and all of the shorelands and everything else. That has to be taken care of before we can even pretend we know what is going on in the ocean.

Chesapeake Bay is one of the classic examples. Twenty years ago I knew dozens and dozens of professors and hard core researchers here. The issues were not about global warming or whatever it is. It is people. We have to solve that problem on the coastlines, up into the wetlands, out of the wetlands into the highlands before we can solve anything that goes on in the ocean.

We have no valves, no levers, anything in the ocean or in the atmosphere. We are not in control. That is the most important information to take home, if I can give you that.

Ms. BORDALLO. Thank you. Thank you, Dr. Sharp.

I wish to thank all of the witnesses for their excellent comments and statements and their participation in the hearing today.

Members of the Subcommittee may have some additional questions for the witnesses, and we will ask you to respond to these in writing. The hearing record will be open for 10 days for these responses.

If there is no further business before the Subcommittee, I would also like to thank Mr. Sali for sitting in for our Ranking Member, Mr. Brown.

The Chairwoman again thanks the Members of the Subcommittee and our witnesses, and the Subcommittee now stands adjourned.

[Whereupon, at 12:35 p.m. the Subcommittee was adjourned.]